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THESIS

NUMERICAL FIELD MODEL SIMULATION OF
FULL-SCALE FIRE TESTS IN A CLOSED
SPHERICAL/CYLINDRICAL VESSEL USING
ADVANCED COMPUTER GRAPHICS TECHNIQUES

by

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SEPTEMBER 1991

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02 2 10 1-3

92-03303



Unclassified

SECURITY CLASSIFICATION OF THIS PAGE

REPORT DOCUMENTATION PAGE				Form Approved OMB No 0704-0188	
1a. REPORT SECURITY CLASSIFICATION Unclassified			1b. RESTRICTIVE MARKINGS		
2a. SECURITY CLASSIFICATION AUTHORITY			3. DISTRIBUTION/AVAILABILITY OF REPORT Approved for public release: Distribution is unlimited		
2b. DECLASSIFICATION/DOWNGRADING SCHEDULE					
4. PERFORMING ORGANIZATION REPORT NUMBER(S)			5. MONITORING ORGANIZATION REPORT NUMBER(S)		
6a. NAME OF PERFORMING ORGANIZATION Naval Postgraduate School		6b. OFFICE SYMBOL (If applicable) ME	7a. NAME OF MONITORING ORGANIZATION Naval Postgraduate School		
6c. ADDRESS (City, State and ZIP Code) Monterey, CA 93943-5000			7b. ADDRESS (City, State, and ZIP Code) Monterey, CA 93943-5000		
8a. NAME OF FUNDING/SPONSORING ORGANIZATION		8b. OFFICE SYMBOL (If applicable)	9. PROCUREMENT INSTRUMENT IDENTIFICATION NUMBER		
8c. ADDRESS (City, State, and ZIP Code)			10. SOURCE OF FUNDING NUMBER		
			PROGRAM ELEMENT NO.	PROJECT NO.	TASK NO.
11. TITLE (Include Security Classification) NUMERICAL FIELD MODEL SIMULATION OF FULL-SCALE FIRE TESTS IN A CLOSED SPHERICAL/CYLINDRICAL VESSEL USING ADVANCED COMPUTER GRAPHICS TECHNIQUES					
12. PERSONAL AUTHOR TIMOTHY G. MCCARTHY					
13a. TYPE OF REPORT Master's Thesis		13b. TIME COVERED FROM _____ TO _____		14. DATE OF REPORT (Year, Month, Day) SEPTEMBER 1991	
15. PAGE COUNT 157					
16. SUPPLEMENTARY NOTATION The views expressed are those of the author and do not reflect the official policy or position of the Department of Defense or the U.S. Government					
17. COSATI CODES			18. SUBJECT TERMS (Continue on reverse if necessary and identify by block numbers)		
FIELD	GROUP	SUB-GROUP	field model, fire simulation, fire modeling, numerical fire model, fires in enclosed vessels, enclosed fires		
19. ABSTRACT (Continue on reverse if necessary and identify by block numbers) Personnel and equipment casualties, caused by shipboard fires have adversely affected overall readiness of the U.S. Navy for centuries. Understanding the phenomena of fire in enclosed spaces, such as those found on surface ships and submarines, will greatly enhance the Navy's ability to combat or prevent them. This computer model was developed for use in conjunction with Fire-1, an experimental fire chamber test facility at the Naval Research Laboratory in Washington, D.C. It is a three-dimensional finite difference model which includes the phenomena of conduction, turbulence, global pressure correction, surface radiation and strong buoyancy flows. Given specific data on heat release, it predicts velocities, temperatures, pressures, densities and viscosities throughout its geometry. It has been reasonably validated by comparison with experiments in Fire-1. Advanced graphics techniques, such as color contouring and three-dimensional vector field plotting, have been applied to make output data more informative. This model, if easily modified to more specific geometries, may become a useful tool for naval architects in the design of the fire safe ship.					
20. DISTRIBUTION/AVAILABILITY OF ABSTRACT XX UNCLASSIFIED/UNLIMITED SAME AS RPT DTIC USERS			21. ABSTRACT SECURITY CLASSIFICATION Unclassified		
22a. NAME OF RESPONSIBLE INDIVIDUAL M.D. Kelleher			22b. TELEPHONE (Include Area Code) (408) 646-2530		22c. OFFICE SYMBOL ME/Kk

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Numerical Field Model Simulation of Full-Scale Fire Tests
in a Closed Spherical/Cylindrical Vessel
Using Advanced Computer Graphics Techniques

by

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Lieutenant, United States Navy
B.S.M.E., University of Rochester, Rochester, N.Y., 1984

Submitted in partial fulfillment of the
requirements for the degree of

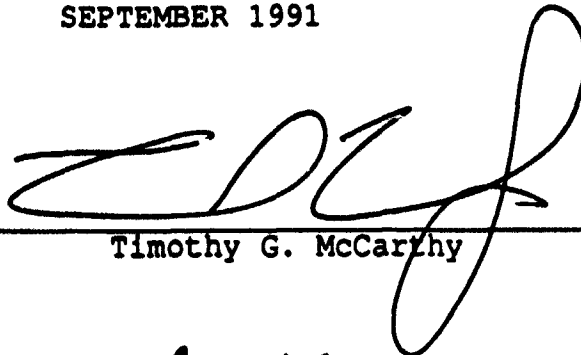
MASTER OF SCIENCE
IN MECHANICAL ENGINEERING

from the

NAVAL POSTGRADUATE SCHOOL

SEPTEMBER 1991

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Approved by:



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ABSTRACT

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LIST OF SYMBOLS AND ABBREVIATIONS

A	Area
A	Finite Difference Coefficients
ARU_	Source Term Variable
AU_	Source Term Variable
C_	Coefficients for Control Volume
C_M	Coefficients for Control Volume
C_P	Coefficients for Control Volume
COND_1	Coefficients for Control Volume
C _{pm}	Mean Isobaric Heat Capacity
CURV	Curvature Terms
CURVN	Orthogonal Curvature Terms
F _{A1-Aj}	View Factor for Radiation Emitted by Surface i and Incident Upon Surface j
G	Gravitational Acceleration
G	Mass Flux Rate
G	Term Used in Radiation Model
g	Curvilinear Base Vector
g _i	Scaling Term
g _{ij}	Covariant Metric Tensor
g ^{ij}	Contravariant Metric Tensor
H	Mixing Length Parameter
h	Scale Factor
h	Convective Heat Transfer Coefficient
H	Enthalpy
J	Total Heat Flux
K	Adjustable Constant
k	Thermal Conductivity
M	Momentum Flux
m	Rate of Change
n	Normal Direction Toward the Vessel Center
P	Pressure
Pr	Prandtl Number
Pr _t	Turbulent Prandtl Number

q	Heat Flux
q_r	Thermal Radiation Energy
R	Universal Gas Constant
R_{-}	Source Term Variable
RR_{-}	Source Term Variable
Ri	Richardson Number
r	Distance Between Two Surfaces
S_f	Source Term
S_{hs}	Heat Source
S_{mp}	Mass Source Term
T	Temperature
t	Time
u	Velocity
V	Volume
VIS	Local Viscosity
X	Length in X-Direction (In QUICK Scheme)

GREEK LETTERS

β	Angles Formed by Radiation Surface Normals
χ	Term Used in Radiation Model
δ_{ij}	Kronecker Delta
ϵ	Emissivity
ϕ	Dissipation Function
μ	Dynamic Viscosity
θ	Directions, θ , r , and ϕ or z
ρ	Fluid Density
σ	Stress
σ	Stefan-Boltzmann Constant
ψ	Term Used in Radiation Model

SUBSCRIPTS

B	Control Volume to the Back
b	Back Control Volume Face
E	Control Volume to the East
EQ	Equilibrium

e	East Control Volume Face
eff	Effective
F	Control Volume to the Front
f	Front Control Volume Face
g	Global
N	Control Volume to the North
n	North Control Volume Face
o	Reference
p	Present Cell
R	Reference
S	Control Volume to the South
s	South Control Volume Face
s	Vessel Wall
W	Control Volume to the West
w	West Control Volume Face
,i	derivative with respect to i
,t	derivative with respect to time

SUPERSCRIPTS

n	Future Value
n-1	Present Value
*	Estimated Value
*	Ventilation Values
'	Correction
^	Prior Value

I. INTRODUCTION

A. BACKGROUND

Annually, the effects of fires on Naval forces are particularly devastating. Ships may be removed from service for repairs which incur costs that may run into the tens of millions of dollars. Personnel casualties, ship down time, equipment repair and replacement all result in a loss of overall readiness of our fleets. The prevention of shipboard fires is of the utmost importance to today's Navy. The understanding of the phenomena of fire, especially in the enclosed spaces found aboard ship, is the first step toward its control and prevention.

The study of fire propagation requires the combined knowledge of fluid dynamics, mass and heat transfer, and combustion. Research into the mechanics of fire and prediction of its behavior will aid engineers in reducing the probability of its ignition and propagation.

There are a number of ways to conduct this research. The most obvious is experimental. But, fires aboard ships are very complex. Often they are in enclosed airtight spaces which allow pressures to build. These spaces may be full of electronic equipment, flammables or toxic substances. Their accessibility may be extremely limited, hampering efforts to

combat fires. An experiment that can accurately account for all these complexities becomes very expensive.

At the Naval Research Laboratory in Washington, D.C., the Navy has built Fire-1, a large pressure vessel designed to model fires aboard submarines, or closed compartments and tanks found on surface ships. It allows fires to be studied under the unique conditions experienced in shipboard fires.

Another method for conducting fire research is the use of a computer model. As computers get faster and can allow for large amounts of data storage, researchers are able to thoroughly model fire phenomena and predict future behavior without the continuous expensive full scale testing of Fire-1. Fires may be modeled by the numerical solution of the governing equations. These models are then verified by the existing data from experiments. With an accurate computer model, several options are available. More complex geometries may be incorporated for specific areas of interest. Entire models of ships may someday be developed to show areas of susceptibility in design. Effects of firefighting methods may be accurately predicted. The savings in running computer codes versus full scale testing are considerable.

Also, now that a high speed VAXSTATION 3100 SPX/RJ19 Model 38 workstation may be dedicated to this particular simulation, computing costs may be minimized. The current code requires approximately 1.0 hours of VAXSTATION CPU per second of fire time.

B. COMPUTER MODELING

Field modeling uses difference forms of the conservation equations of mass, momentum, energy and species. These are used to calculate temperature, velocity, pressure, viscosity and density at specific points in the volume of interest. This volume, being the compartment studied, is broken down to finite volume elements. The conservation equations are solved at this level for discrete time steps from a known initial condition. Additional models of physical effects such as radiation, turbulence, and wall conduction are included to increase the simulation's validity. This method requires large amounts of computer memory and high speed processors.

Much research has been done previously and has provided the basis for this thesis. At the University of Notre Dame [Refs. 1 and 2] work has been conducted involving aircraft cabin fires using a two dimensional finite difference field model which predicts velocity, temperature and smoke concentration inside the passenger area of an aircraft. Nicolette et al. [Ref. 3] developed a two dimensional model of transient cooling by natural convection. It utilized a fully transient, semi-implicit upwind differencing scheme and global pressure correction that was verified experimentally.

More recent [Refs. 4 through 12] studies have developed numerical solutions for three dimensional rectangular enclosures in which non-linear partial differential equations were solved by finite difference methods. Models for three

dimensional cylindrical coordinate buoyant flows [Refs. 13 through 19] have also been developed, and deal mainly with horizontal annuli with differential temperatures specified at inner and outer cylindrical walls. Smutek et al. [Ref. 18] studied buoyant flows in horizontal cylinders with differentially heated ends at low Rayleigh numbers ($74 \leq Ra \leq 18700$). Yang et al. [Ref. 19] conducted a similar study but with high Rayleigh numbers ($10^4 \leq Ra \leq 10^7$).

Studies have also been done on methods for decoupling the pressure terms from the Navier-Stokes Equation. The stream function-vorticity formulation has been used [Refs. 13 through 18] to calculate natural convection in various geometries. There are problems with this method such as instability at high Rayleigh numbers. Yang et al. [Ref. 19] address this problem and suggest using a primitive variable formulation when using arbitrary orthogonal coordinates.

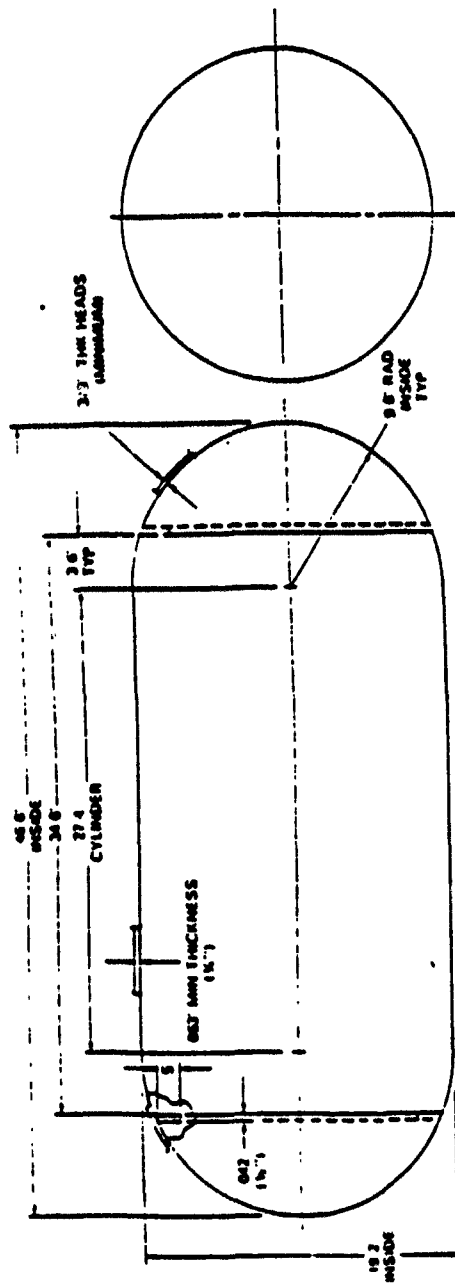
Natural convection in spherical annuli was studied by Ozoe [Ref. 20] utilizing velocity-vector formulation. Field models involving prediction of fires in enclosures have been studied by Baum and Rehm [Refs. 21 through 24]. These include time dependent Boussinesq equations to simulate three dimensional buoyant convection and smoke aerosol coagulation. Field models involving three dimensional enclosures and employing the Boussinesq approximation, were studied by Bagnaro et al. [Ref. 25] and by Markatos and Pericleous [Ref. 26].

In this thesis, the numerical method developed by Yang et al. [Ref. 19] using primitive variable finite difference discretization in generalized orthogonal coordinates is employed. This method can handle complex geometries and has the numerical stability characteristic of primitive variable formulation.

C. FIRE-1 TEST FACILITY

An experimental test facility called Fire-1, has been constructed at the Naval Research Laboratory to study the behavior of fires in enclosed spaces found on submarines and surface ships. Since the computer code presented in this thesis models the geometry of Fire 1, this section contains a brief description of that facility. More information may be obtained from Alexander et al. [Ref. 27]. Figure 1.1 shows the basic layout. Fire-1 is a cylindrical pressure vessel with hemispherical endcaps. It is constructed of 3/8-inch ASTM 295 Grade C steel and can withstand internal pressures up to 89.7 psi and temperatures of 450°F. Its total length is 46.6 feet long. The cylinder and endcap radii are both 9.6 feet. Rupture discs are placed at each endcap to prevent failure due to overpressurization.

Figure 1.2 shows the instrumentation layout. An array of chromel-alumel thermocouples with ceramic insulation and stainless steel jackets, are placed near each endcap. Additional thermocouples are placed on the chamber walls, both



NOTES UNLESS OTHERWISE SPECIFIED

- 1 ALL DIMENSIONS IN FEET
- 2 MATERIAL A 516 205 GRADE C STEEL
- 3 FINISH PRIME COAT (OUTSIDE SURFACE & PAINT)
- 4 CONSTRUCTION TO PRESSURE TEST PER
A S ME CODE FOR P S P ST WORKING
PRESSURE INTERNAL AT MRL
- 5 INSTALLATION AT MRL
- 6 TANK VOLUME
SPHERE 3.18 CU FT
CYLINDER 7.93 CU FT
TOTAL 11.11 CU FT ± 3%
- 7 EXTENSOR LIFTING LUGS OPTIONAL
- 8 WELDED CONSTRUCTION

Fig 1 -- Blueprint drawing of 324 m³ chamber

Figure 1.1 Drawing of Fire-1 Test Vessel.

inside and out, to monitor inside and outside wall temperatures. A specific test might call for placement of extra thermocouples or radiometers at various other locations. These are arranged as required by the experiment.

Burn rate data is obtained using round, tapered edge fire pans of various cross sectional areas, and a constant level, liquid fuel supply system. To date, this data has been the least accurate in the experiment. The system and its calibration are described by Alexander et al. [Ref. 27]. Smoke concentration can be measured using video cameras, particle analysis and obscuration with laser detectors.

To more completely represent shipboard compartments, the facility has a number of features. First is the installation of two removable decks, one at the midheight, the other at three feet above the bottom. Either grated or solid deck plating is used depending on desired configuration. Second is the installation of a nitrogen pressurization system used as an extinguishing agent. Its performance is being tested for possible use combatting actual fires.

D. THE COMPUTER PROGRAM

This computer model is a joint project undertaken by the Naval Postgraduate School and the University of Notre Dame. It represents a low cost alternative to full scale test using Fire-1. With proper modifications, used in conjunction with

Fire-1, it will test effectiveness of damage-control systems and evaluate new ship designs.

In the work by Nies [Ref. 28], the code was based on a rectangular geometry with the volume identical to Fire-1. This was a three dimensional, finite volume model using primitive variables. Turbulence, wall conduction, and a global pressure correction factor were also included. Due to the unreliability of burn rate data, Nies [Ref. 28] devised a scheme for computing a heat release rate by using experimental pressure curves as input.

The actual geometry of Fire-1 was employed by Raycraft [Ref. 29]. Using its spherical/cylindrical coordinate system and detailed formulation of radiation surface view factors, global pressure correction, conduction and turbulence, the code created an extremely viable model for use with Fire-1. There were the continued problems with simulating the heat release data which were partially resolved by numerically fitting experimental burn rate data available.

Houck [Ref. 31] included a model which simulated internal forced circulation. It was compared to data run without circulation and it was concluded that circulation had minimal effects on the overall velocity and temperature profiles.

In this thesis, advanced three dimensional and color graphics techniques are used to present data generated using the previously developed codes. Using the VAXSTATION 3100 SPX and the software CA-DISSPLA [Ref. 31] the data is presented in

a more informative fashion. Color graphics are used to present isotherm profiles and three dimensional vector fields will represent velocity profiles.

II. DESCRIPTION OF NUMERICAL MODEL

A. GOVERNING EQUATIONS

The model is based on the system of conservation equations which govern the behavior of fluid flow and heat transfer in gases. These equations are in differential form and are presented in generalized curvilinear coordinates using standard tensor notation. Nies [Ref. 28] based his model on rectangular geometry using Cartesian coordinates. Raycraft [Ref. 29] refined the model to describe the exact geometry of Fire-1 and included surface radiation. Houck [Ref. 30] described the transformation to curvilinear coordinates, used by Yang et al. [Ref. 19], in detail and the following forms of the governing equations are obtained.

The equation of continuity is:

$$\rho_t + \frac{1}{\sqrt{g}} \frac{\partial}{\partial \theta^i} \left\{ \sqrt{g} \rho \frac{u^i}{h_i} \right\} = 0 \quad (2.1)$$

The energy equation becomes:

$$\begin{aligned} & \left(\rho C_{pm} T \right)_t + \frac{1}{\sqrt{g}} \frac{\partial}{\partial \theta^i} \left\{ \sqrt{g} \rho C_{pm} u^i \frac{T}{h_i} \right\} \\ & = \frac{1}{\sqrt{g}} \frac{\partial}{\partial \theta^i} \left\{ \sqrt{g} \frac{k_{eff} T_{,i}}{h_i^2} \right\} + S_f \end{aligned} \quad (2.2)$$

where the source term, S_f is:

$$S_f = \mu\Phi + P \frac{1}{\sqrt{g}} \frac{\partial}{\partial \theta^i} \left\{ \sqrt{g} \frac{u^i}{h_i} \right\} + S_{hs} \quad (2.3)$$

and the dissipation term is:

$$\begin{aligned} \Phi = & 2 \left\{ \left(\frac{u^i}{h_i} \right)_{,j} \right\} \delta_{ij} \\ & + \left\{ \left(\frac{u^i}{h_i} \right)_{,j} (1 - \delta_{ij}) \right\}^2 - \frac{2}{3} \left\{ \left(\frac{u^i}{h_i} \right)_{,i} \right\}^2 \end{aligned} \quad (2.4)$$

S_{hs} is the heat source term which is zero everywhere except nodes at the fire's location and δ_{ij} is the Kronecker Delta.

The momentum equation becomes:

$$\begin{aligned} & (\rho u^i)_{,i} + \frac{1}{\sqrt{g}} \frac{\partial}{\partial \theta^i} \left\{ \sqrt{g} \frac{u^i u^j}{h_j} \right\} \\ & = - \frac{P_{,i}}{h_i} + \rho G^i + \frac{1}{\sqrt{g}} \frac{\partial}{\partial \theta^j} \left\{ \frac{\sqrt{g} \sigma_j^i}{h_j} \right\} \\ & - \frac{1}{h_i h_j} \frac{\partial h_i}{\partial \theta^j} (\rho u^i u^j - \sigma_j^i) + \frac{1}{h_i h_j} \frac{\partial h_j}{\partial \theta^i} (\rho u^j u^i - \sigma_i^j) \end{aligned} \quad (2.5)$$

where the stress tensor is:

$$\begin{aligned} \sigma_j^i = & \mu_{eff} \left\{ \frac{h_j}{h_i} \frac{\partial}{\partial \theta^i} \left(\frac{u^j}{h_j} \right) \right. \\ & \left. + \frac{h_i}{h_j} \frac{\partial}{\partial \theta^j} \left(\frac{u^i}{h_i} \right) + \frac{\delta_{ij}}{h_i h_j} \frac{\partial q_{ii}}{\partial \theta^a} \left(\sqrt{g} \frac{u^a}{h_a} \right) \right\} \end{aligned} \quad (2.6)$$

Effective conductivity k_{eff} and dynamic viscosity μ_{eff} include both laminar and turbulent terms. Additional terms found in

the momentum equation are due to coriolis and centrifugal effects.

The equations of state remain unchanged through coordinate transformations and are given as:

$$P = \rho RT \quad (2.7)$$

$$H = C_{pm} (T - T_R) \quad (2.8)$$

B. INITIAL AND BOUNDARY CONDITIONS

In order to solve this system of differential equations, boundary and initial conditions must be determined and applied.

1. Initial Conditions

The initial conditions for the model are determined from conditions present just prior to ignition in Fire-1. The air inside is totally at rest. The temperature is equal to ambient temperature and is assumed uniform throughout. Therefore, in the model, the entire velocity field is set to zero and the non-dimensional temperature field is set to 1.0 which corresponds to ambient temperature. Pressure and density distributions are at static equilibrium.

2. Boundary Conditions

Since the vessel wall is a solid boundary which is nonporous, the velocities, both normal and tangential to the wall, are zero. Mass flux across the wall is also zero. The temperature of the wall is equal to the temperature of the

fluid at the interface. Conservation of energy must also be met at the interface. The following three equations summarize wall boundary conditions:

$$u_{surf}^i = 0 \quad (2.9)$$

$$T_{fluid} = T_{solid} \quad (2.10)$$

$$q_r - k_f \frac{\partial T}{\partial n} \Big|_f = -k_s \frac{\partial T}{\partial n} \Big|_{solid} \quad (2.11)$$

where q_r is the heat flux arriving at the solid/fluid interface and n is the normal direction of the surface into the enclosure. There is conduction through the wall and convection from outer surface to ambient temperature.

Due to singularities occurring at $r=0$ in cylindrical/spherical coordinates, special care must be taken at the origin. Yang et al. [Ref. 19:pp. 167-168] discuss methods for addressing this problem. In this model, two consecutive control volumes are placed at $r=0$ and continuity is applied.

C. MODELS OF PHYSICAL PHENOMENA

1. Wall Conduction Model

This model calculates heat loss from the vessel through the walls to the environment. It assumes one dimension, unsteady heat flow and constant convective heat

transfer coefficient at the wall's exterior. The energy equation is:

$$(\rho_s C_{ps} T)_t = \frac{1}{\sqrt{g}} \frac{\partial}{\partial \theta^i} (\sqrt{g} k_s T_{,j} g^{ij}) + S \quad (2.12)$$

2. Turbulence Model

The turbulence model is a simple algebraic method used to predict mean flow quantities for incompressible boundary layer flows. Developed by Nee and Liu [Ref. 33], the model determines the effective viscosity in recirculating buoyant flows with large variations in turbulence levels. The equation, transformed into generalized curvilinear coordinates, is:

$$\frac{\mu_{eff}}{\mu_o} = 1 + \frac{\left(\frac{l}{H} \right)^2 \sqrt{\left(\frac{1}{h_j} \frac{\partial u^j}{\partial \theta^j} \right) (1 - \delta_1^j)}}{2 + \frac{Ri}{Pr_t}} \quad (2.13)$$

where ℓ/H is a non-dimensional mixing length parameter given as:

$$\frac{\ell}{H} = K \left\{ \frac{\sqrt{u^i u^i}}{\sqrt{\sum_{ij} \left(\frac{1}{h_j} \frac{\partial u^i}{\partial \theta^j} \right)^2}} + \frac{\sqrt{\sum_{ij} \left(\frac{1}{h_j} \frac{\partial u^i}{\partial \theta^j} \right)^2}}{\sqrt{\sum_{ij} \left(\frac{1}{h_i h_j} \frac{\partial^2 u^i}{\partial \theta^i \partial \theta^j} \right)^2}} \right\} \quad (2.14)$$

K is an adjustable constant and the Richardson Number, Ri , is given as:

$$Ri = \frac{H}{u_z^3} \frac{\left(\frac{\partial T}{\partial n} \right) \bar{n} \cdot \bar{g}}{\left[\left(\frac{\partial u^1}{\partial n} \right) \bar{n} \cdot \bar{g} \right]^2 + \left[\left(\frac{\partial u^2}{\partial n} \right) \bar{n} \cdot \bar{g} \right]^2 + \left[\left(\frac{\partial u^3}{\partial n} \right) \bar{n} \cdot \bar{g} \right]^2} \quad (2.15)$$

\bar{n} is a unit vector in the opposite direction of gravity.

Pr_t is the turbulent Prandtl number which is also used to compute the effective conductivity.

$$k_{eff} = \frac{1}{Pr} + \frac{1}{Pr_t} \frac{\mu_{eff}}{\mu_o} \quad (2.16)$$

Pr is the molecular Prandtl number.

3. Surface Radiation Model

Raycraft [Ref. 29, pp. 24-44] describes this model in detail. Summarizing, the radiation model considers only surface radiation. Smoke and gases are considered transparent. Inside the model, walls and flame areas are treated as surfaces. Each surface is considered to be gray and diffuse. Sparrow and Cess [Ref. 34] discuss the net radiosity method upon which this model is based.

Net rate of heat loss per unit area is given as:

$$\frac{Q_i}{A_i} = \sum_{j=1}^N G_{ij} \sigma T_j^4 \quad (2.17)$$

where

$$G_{ij} = \frac{\epsilon_i}{1 - \epsilon_i} (\delta_{ij} - \psi_{ij}) \quad (2.18)$$

$$\psi_{ij} = \chi_{ij}^{-1}$$

$$\chi_{ij} = \frac{\delta_{ij} - (1 - \epsilon_i) F_{Ai-Aj}}{\epsilon_i} \quad (2.19)$$

F_{Ai-Aj} is the view factor of radiation emitted by surface i onto surface j . The general equation is given by

$$F_{Ai-Aj} = \frac{1}{A_i} \int_{A_i} \int_{A_j} \frac{\cos \beta_i \cos \beta_j dA_i dA_j}{\pi r^2} \quad (2.20)$$

III. FINITE VOLUME CALCULATIONS

A. INTRODUCTION

The numerical model's independent variables are time and three space coordinates. Dependent variables consist of the three dimensional components of velocity, temperature, pressure and density. These six unknowns require six equations for solution. They are the continuity equation (Eq. (2.1)), the three momentum equations (Eq. (2.5)), the energy equation (Eq. (2.2)), and the equations of state (Eq. (2.7) and (2.8)). Doria [Ref. 35] discretized these equations in a method similar to this particular model based on the generalized form presented by Patanker [Ref. 36]. Doria applied the conservation equations in integral form to each control volume creating a set of finite difference equations which would lead to a solution.

Each control volume, or cell, surrounds a nodal point where one value of each property is constant throughout. The center nodal point determines pressure density and temperature. The grid determining velocities are staggered by one-half a cell length. Patanker [Ref. 36:pp. 115-120] describes how this alleviates two problems: the pressure differential between the two adjacent nodes, which ultimately determines the velocity at the node in question, is based on

a length which is half as long as in the unstaggered cell (this reduces error by one half); second, stability is gained by this stagger which precludes unrealistic, wavy oscillatory velocity fields, since the difference of adjacent velocities are used to satisfy continuity.

Since primitive variables are used versus the stream function, the pressure term coupling between equations must be handled specially. An iterative procedure estimates pressure and then pressure is corrected to ensure continuity is satisfied for each cell. A local pressure correction is discussed by both Patanker [Ref. 36:pp. 120-128] and Doria [Ref. 35:pp. 26-32]. A global pressure correction is included in the model to handle net energy changes and is described by Nicolette, et al. [Ref. 3].

The finite difference equations are solved iteratively. Non-linear problems like fluid flow are difficult to force convergence to final solution. Many schemes have been developed to obtain the flow problem solution. Each method has its problems and instabilities. This model employs the Quadratic Upstream Interpolation for Convective Kinematics, or QUICK, developed by Leonard [Ref. 37]. QUICK estimates values and gradients of transport variables at the faces of the cells. It has the accuracy of central finite difference schemes and the stability of convective diffusion terms found in upwind differencing. Yang [Ref. 12] applied the QUICK scheme to coupled momentum energy and pressure equation

solutions for three-dimensional flow in tilted rectangular enclosures.

In this chapter, the governing equations will be applied to the specialized control volumes of the model. They will be put in integral form and discretized according to the QUICK scheme. Pressure correction from iteration will also be applied.

B. CONTROL VOLUME ANALYSIS

At the center of each elemental control volume, or cell, lies the grid point of interest. At this point, the model determines the unknown values of the dependent variables. Denoting this grid point as $P(i, j, k)$ we define its neighbors as: East $(i+1, j, k)$, West $(i-1, j, k)$, North $(i, j+1, k)$, South $(i, j-1, k)$, Front $(i, j, k+1)$, and Back $(i, j, k-1)$. The boundaries around P are designated by lower case letters $e, w, n, s, f,$ and b . Typical spherical and cylindrical cells are shown in Figures 3.1 and 3.2 respectively.

Figure 3.3 shows the basic two dimensional cell used to determine pressure, density and temperature. In contrast, Figure 3.4 shows the staggered grid used to determine velocities. The velocity u_1 is located on the west face; u_2 is located on the south face and u_3 is located on the back face (not shown). The superscripts on the velocities designate

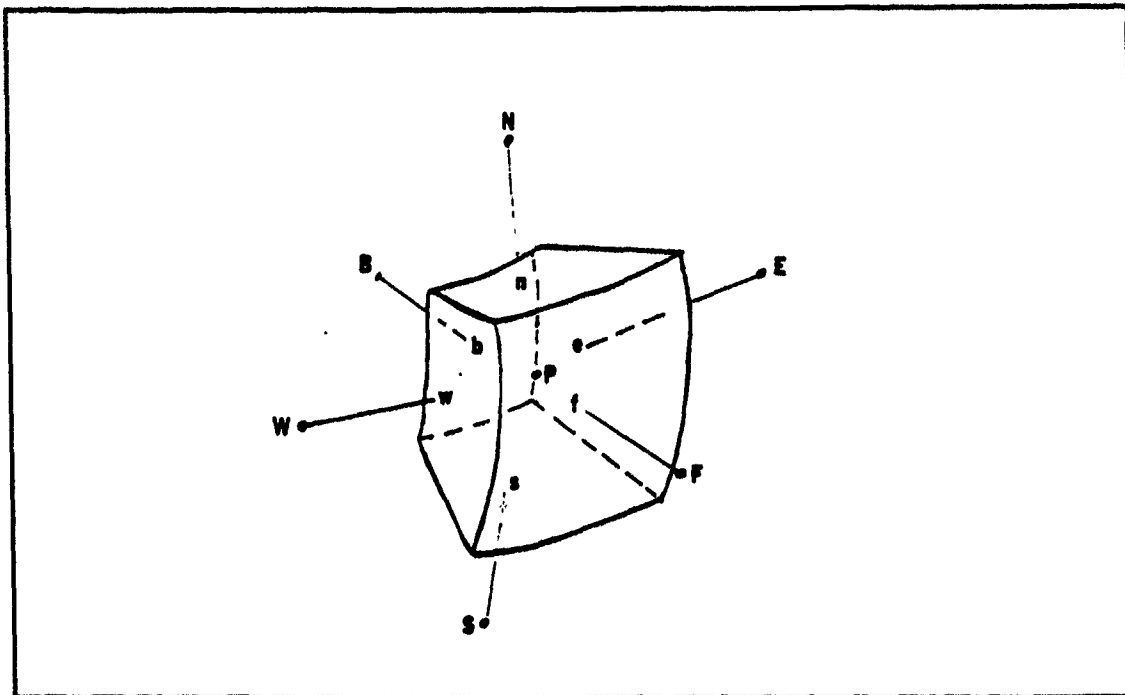


Figure 3.1 Basic Spherical Cell.

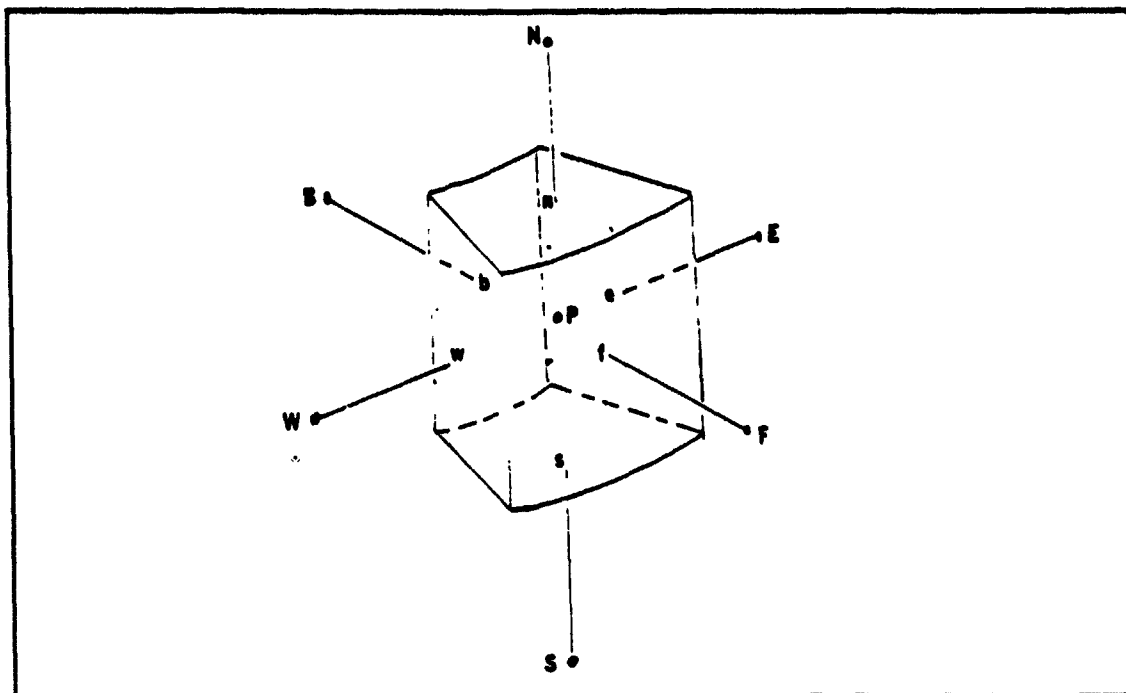


Figure 3.2 Basic Cylindrical Cell.

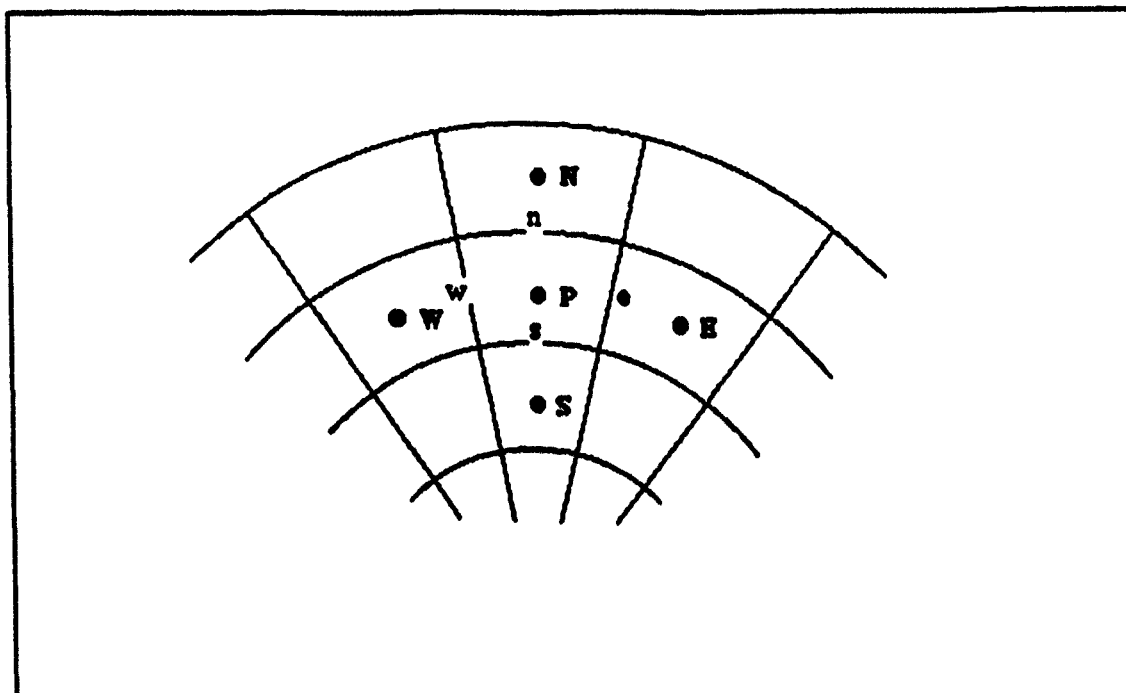


Figure 3.3 Two Dimensional Cell.

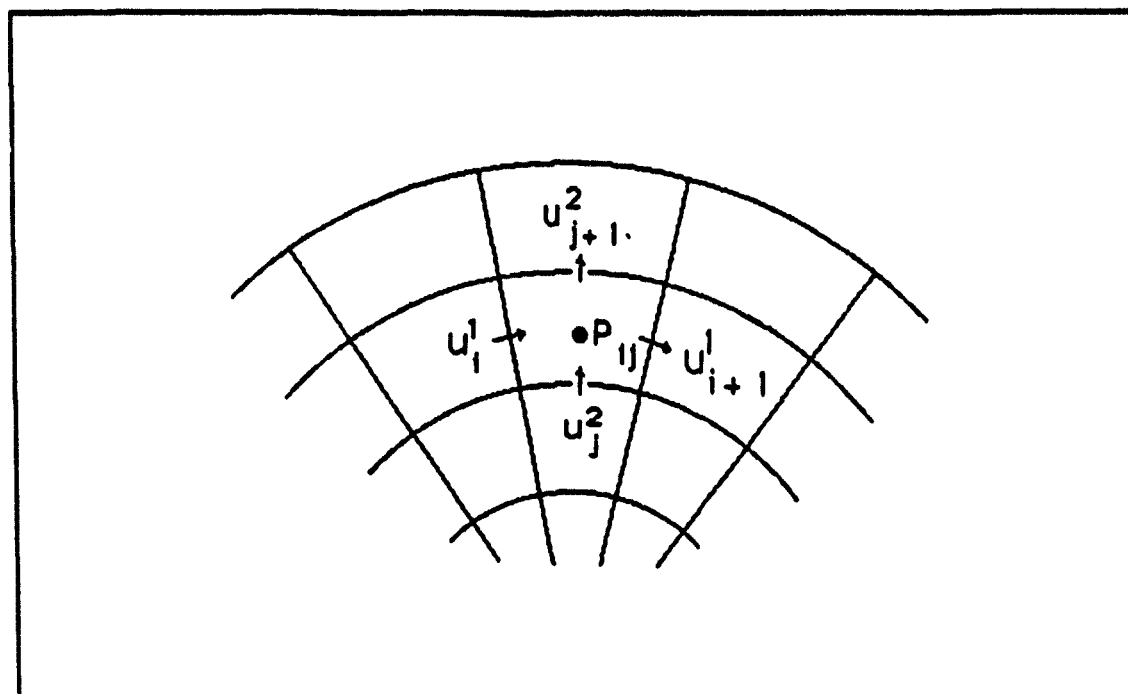


Figure 3.4 Two Dimensional Staggered Cell.

coordinate direction. These velocities are staggered in location by one-half cell length from the primary cell.

C. INTEGRATION OF THE CONSERVATION EQUATIONS

The conservation equations are integrated over each cell volume. From this point, they can be discretized into finite difference equations. The integral form of the continuity equation is:

$$\begin{aligned} & \int \frac{\partial \rho}{\partial t} h_1 h_2 h_3 \partial \theta^1 \partial \theta^2 \partial \theta^3 \\ & + \int \left[\frac{\partial}{\partial \theta^1} (\rho u^1 h_2 h_3) + \frac{\partial}{\partial \theta^2} (\rho u^2 h_3 h_1) \right. \\ & \left. + \frac{\partial}{\partial \theta^3} (\rho u^3 h_1 h_2) \right] \partial \theta^1 \partial \theta^2 \partial \theta^3 \\ & = 0 \end{aligned} \quad (3.1)$$

The energy equation becomes:

$$\begin{aligned} & \int \frac{\partial (\rho C_{pm} T)}{\partial t} h_1 h_2 h_3 \partial \theta^1 \partial \theta^2 \partial \theta^3 \\ & + \int \left[\frac{\partial}{\partial \theta^1} (\rho C_{pm} u^1 T h_2 h_3) + \frac{\partial}{\partial \theta^2} (\rho C_{pm} u^2 T h_1 h_3) \right. \\ & \left. + \frac{\partial}{\partial \theta^3} (\rho C_{pm} u^3 T h_1 h_2) \right] \partial \theta^1 \partial \theta^2 \partial \theta^3 \\ & - \int \left[\frac{\partial}{\partial \theta^1} (q^1 h_2 h_3) + \frac{\partial}{\partial \theta^2} (q^2 h_1 h_3) + \frac{\partial}{\partial \theta^3} (q^3 h_1 h_2) \right] \\ & \cdot \partial \theta^1 \partial \theta^2 \partial \theta^3 + \int s h_1 h_2 h_3 \partial \theta^1 \partial \theta^2 \partial \theta^3 \end{aligned} \quad (3.2)$$

where:

$$q^i = \frac{-k}{h_i} \frac{\partial T}{\partial \theta^i} \quad (3.3)$$

The momentum equations become:

$$\begin{aligned}
 & \int \frac{\partial}{\partial t} (\rho u^i) h_1 h_2 h_3 \partial \theta^1 \partial \theta^2 \partial \theta^3 \\
 & + \int \frac{\partial}{\partial \theta^j} \left[\left(\frac{h_1 h_2 h_3}{h_j} \right) \rho u^i u^j \right] \partial \theta^1 \partial \theta^2 \partial \theta^3 \\
 & = \int \frac{-\partial}{\partial \theta^i} \left(p \frac{h_1 h_2 h_3}{h_i} \right) \partial \theta^1 \partial \theta^2 \partial \theta^3 \\
 & + \int \rho G_i h_1 h_2 h_3 \partial \theta^1 \partial \theta^2 \partial \theta^3 \quad (3.4) \\
 & + \int \frac{\partial}{\partial \theta^j} \left(\sigma^{ij} \frac{h_1 h_2 h_3}{h_i h_j} \right) \partial \theta^1 \partial \theta^2 \partial \theta^3 \\
 & - \int \frac{h_1 h_2 h_3}{h_i h_j} \left[\frac{\partial h_i}{\partial \theta^j} (\rho u^j u^i - \sigma^{ij}) \right] \partial \theta^1 \partial \theta^2 \partial \theta^3 \\
 & + \int \frac{h_1 h_2 h_3}{h_j h_i} \left[\frac{\partial h_j}{\partial \theta^i} (\rho u^j u^i - \sigma^{ij}) \right] \partial \theta^1 \partial \theta^2 \partial \theta^3
 \end{aligned}$$

D. DISCRETIZATION OF THE CONTINUITY EQUATION

To provide maximum stability and accuracy for the model, three finite differencing schemes are utilized. Forward differencing is used for time dependence, central differencing is used for diffusion terms and the QUICK algorithm is used for the convective terms.

In forward differencing the future value of the time dependent variable is predicted from its previous value plus an additional term derived from the previously known slope multiplied by the time step Δt . For example the new value for

density ρ^n is calculated using the old value ρ^{n-1} plus the extra term:

$$\rho^n = \rho^{n-1} + m\Delta t \quad (3.5)$$

The integrand in the continuity equation (3.1) becomes:

$$\frac{\partial \rho}{\partial t} dV = \frac{\rho^n - \rho^{n-1}}{\Delta t} h_1 h_2 h_3 \Delta\theta^1 \Delta\theta^2 \Delta\theta^3 = \frac{\rho^n - \rho^{n-1}}{\Delta t} \Delta V \quad (3.6)$$

Evaluating the integral, Equation (3.1) becomes:

$$\begin{aligned} & (\rho^n - \rho^{n-1}) \frac{\Delta V}{\Delta t} + [\rho u^1 h_2 h_3 d\theta^2 d\theta^3]_e - [\rho u^1 h_2 h_3 d\theta^2 d\theta^3]_w \\ & + [\rho u^2 h_1 h_3 d\theta^1 d\theta^3]_n - [\rho u^2 h_1 h_3 d\theta^1 d\theta^3]_s \\ & + [\rho u^3 h_1 h_2 d\theta^1 d\theta^2]_f - [\rho u^3 h_1 h_2 d\theta^1 d\theta^2]_b = 0 \end{aligned} \quad (3.7)$$

The mass flux, G , must be calculated at each face:

$$G_e = (\rho u^1)_e = u_e^1 \left[\frac{\rho_p (h_1 \Delta\theta^1)_{i+1} + \rho_e (h_1 \Delta\theta^1)_i}{(h_1 \Delta\theta^1)_{i+1} + (h_1 \Delta\theta^1)_i} \right] \quad (3.8)$$

$$G_w = (\rho u^1)_w = u_w^1 \left[\frac{\rho_p (h_1 \Delta\theta^1)_{i-1} + \rho_w (h_1 \Delta\theta^1)_i}{(h_1 \Delta\theta^1)_{i-1} + (h_1 \Delta\theta^1)_i} \right] \quad (3.9)$$

$$G_n = (\rho u^2)_n = u_n^2 \left[\frac{\rho_p (h_2 \Delta\theta^2)_{j+1} + \rho_n (h_2 \Delta\theta^2)_j}{(h_2 \Delta\theta^2)_{j+1} + (h_2 \Delta\theta^2)_j} \right] \quad (3.10)$$

$$G_s = (\rho u^2)_s = u_s^2 \left[\frac{\rho_p (h_2 \Delta\theta^2)_{j-1} + \rho_s (h_2 \Delta\theta^2)_j}{(h_2 \Delta\theta^2)_{j-1} + (h_2 \Delta\theta^2)_j} \right] \quad (3.11)$$

$$G_f = (\rho u^3)_f = u_f^3 \left[\frac{\rho_p (h_3 \Delta \theta^3)_{k+1} + \rho_F (h_3 \Delta \theta^3)_k}{(h_3 \Delta \theta^3)_{k+1} + (h_3 \Delta \theta^3)_k} \right] \quad (3.12)$$

$$G_b = (\rho u^3)_b = u_b^3 \left[\frac{\rho_p (h_3 \Delta \theta^3)_{k-1} + \rho_B (h_3 \Delta \theta^3)_k}{(h_3 \Delta \theta^3)_{k-1} + (h_3 \Delta \theta^3)_k} \right] \quad (3.13)$$

The areas of the faces of the cell are given as:

$$A_{e,v} = (h_2 \Delta \theta^2 h_3 \Delta \theta^3)_{e,v} \quad (3.14)$$

$$A_{n,s} = (h_1 \Delta \theta^1 h_3 \Delta \theta^3)_{n,s} \quad (3.15)$$

$$A_{f,b} = (h_1 \Delta \theta^1 h_2 \Delta \theta^2)_{f,b} \quad (3.16)$$

In final finite difference form the continuity equation becomes:

$$\frac{(\rho^n - \rho^{n-1}) \Delta V}{\Delta t} + G_e - G_v + G_n - G_s + G_f - G_b = S_{np} \quad (3.17)$$

S_{np} is the mass source term. As this residual approaches zero, the solution approach the exact solution. Iterations occur until S_{np} reaches a specific, extremely small, cut off value.

E. DISCRETIZATION OF THE ENERGY EQUATION

Integrating over the control volume, the energy equation becomes:

$$\begin{aligned}
 & [(\rho C_{pm} T)^n - (\rho C_{pm} T)^{n-1}] \frac{\Delta V}{\Delta t} + G_e (C_{pm} T)_e A_e \\
 & - G_w (C_{pm} T)_w A_w + G_n (C_{pm} T)_n A_n - G_s (C_{pm} T)_s A_s + \\
 & G_f (C_{pm} T)_f A_f - G_b (C_{pm} T)_b A_b \\
 & = k_e A_e \left(\frac{\partial T}{h_1 \partial \theta^1} \right)_e - k_w A_w \left(\frac{\partial T}{h_1 \partial \theta^1} \right)_w \\
 & + k_n A_n \left(\frac{\partial T}{h_2 \partial \theta^2} \right)_n - k_s A_s \left(\frac{\partial T}{h_2 \partial \theta^2} \right)_s \\
 & + k_f A_f \left(\frac{\partial T}{h_3 \partial \theta^3} \right)_f - k_b A_b \left(\frac{\partial T}{h_3 \partial \theta^3} \right)_b + S_f \Delta V
 \end{aligned} \tag{3.18}$$

where S_f is the source term including dissipation, radiation, pressure work and heat sources. The total heat flux, J , resulting from convection and conduction is:

$$J_{e,w}^1 = \left[(\rho C_{pm} u^1 T) - k_{eff} \frac{\partial T}{h_1 \partial \theta^1} \right]_{e,w} \tag{3.19}$$

$$J_{n,s}^2 = \left[(\rho C_{pm} u^2 T) - k_{eff} \frac{\partial T}{h_2 \partial \theta^2} \right]_{n,s} \tag{3.20}$$

$$J_{f,b}^3 = \left[(\rho C_{pm} u^3 T) - k_{eff} \frac{\partial T}{h_3 \partial \theta^3} \right]_{f,b} \tag{3.21}$$

The final finite difference form of the energy equation becomes:

$$\begin{aligned} & [(\rho C_{pm} T)^n - (\rho C_{pm} T)^{n-1}] \frac{\Delta V}{\Delta t} + J_e^i A_e \\ & - J_w^i A_w + J_n^i A_n - J_s^i A_s + J_f^i A_f - J_b^i A_b = S_f \Delta V \end{aligned} \quad (3.22)$$

The term $(\rho u^i C_{pm} T)$ in the flux equations give rise to difficulties since C_{pm} , ρ and T are evaluated at the nodal point instead of the surface of the cell. Thus, fluxes are determined from values of ρ , T , and C_{pm} at P and its neighbors.

The QUICK Scheme is used to determine accurate values of the dependent variables at the control volume surfaces with stable properties. QUICK couples the stability of upwind differencing with the accuracy of central differencing. It is achieved by using a parabolic polynomial interpolation to fit the control volume at three consecutive nodal points. Two nodes are located on either side of the surface and one is located upstream. Yang [Ref. 12:pp. 77-89] discusses QUICK for one, two and three dimensions. Houck [Ref. 30:pp. 37-50] and Raycraft [Ref. 29:pp. 63-74] used the QUICK scheme for the energy equations and that method is repeated here.

Figure 3.5 from Raycraft [Ref. 29:pp. 64] shows the one dimensional scheme for the quadratic interpolation of a non-uniform grid.

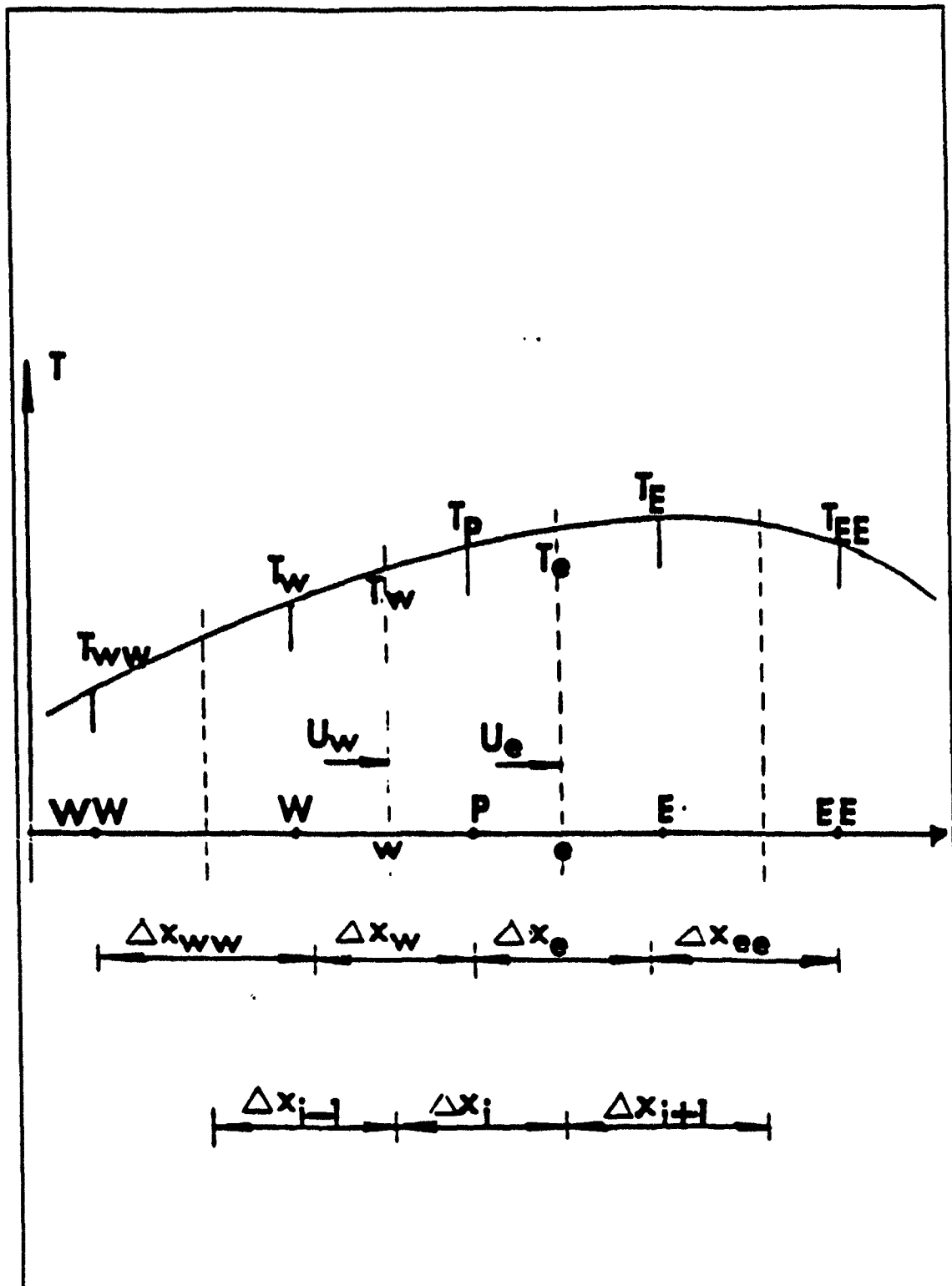


Figure 3.5 One Dimensional Quadratic Interpolation Scheme.

It is given by the equations

$$(\rho C_{pm} u T)_e = G_e C_{pm} \left[\left(\frac{T_p + T_e}{2} \right) - \frac{1}{8} \text{curv}_e \right] \quad (3.23)$$

$$(\rho C_{pm} v T)_v = G_v C_{pm} \left[\left(\frac{T_p + T_v}{2} \right) - \frac{1}{8} \text{curv}_v \right] \quad (3.24)$$

where the upstream weighted curvature terms are:

$$\begin{aligned} \text{curv}_e &= \frac{\Delta X_e^2}{\Delta X_i} \left[\frac{T_e - T_p}{\Delta X_e} - \frac{T_p - T_v}{\Delta X_v} \right] \text{ if } G_e > 0 \\ &= \frac{\Delta X_e^2}{\Delta X_{i+1}} \left[\frac{T_{ee} - T_e}{\Delta X_{ee}} - \frac{T_e - T_p}{\Delta X_e} \right] \text{ if } G_e < 0 \end{aligned} \quad (3.25)$$

$$\begin{aligned} \text{curv}_v &= \frac{\Delta X_v^2}{\Delta X_{i+1}} \left[\frac{T_p - T_v}{\Delta X_v} - \frac{T_v - T_{vv}}{\Delta X_{vv}} \right] \text{ if } G_v > 0 \\ &= \frac{\Delta X_v^2}{\Delta X_i} \left[\frac{T_e - T_p}{\Delta X_e} - \frac{T_p - T_v}{\Delta X_v} \right] \text{ if } G_v < 0 \end{aligned} \quad (3.26)$$

and

$$\begin{aligned} \Delta X_e &= \frac{1}{2} (\Delta X_i + \Delta X_{i+1}) \\ \Delta X_v &= \frac{1}{2} (\Delta X_i + \Delta X_{i-1}) \\ \Delta X_{ee} &= \frac{1}{2} (\Delta X_{i+1} + \Delta X_{i+2}) \\ \Delta X_{vv} &= \frac{1}{2} (\Delta X_{i-1} + \Delta X_{i-2}) \end{aligned} \quad (3.27)$$

In generalized orthogonal coordinates the convective flux terms become:

$$(\rho C_{pm} u^1 T)_e = G_e C_{pm} \left(\frac{T_p + T_E}{2} - \frac{1}{8} \text{curvn}_e \right) \quad (3.28)$$

$$(\rho C_{pm} u^2 T)_w = G_w C_{pm} \left(\frac{T_p + T_w}{2} - \frac{1}{8} \text{curvn}_w \right) \quad (3.29)$$

where

$$\begin{aligned} \text{curvn}_e &= \frac{(h_1 \Delta \theta^1)_e^2}{(h_1 \Delta \theta^1)_i} \left[\frac{T_E - T_p}{(h_1 \Delta \theta^1)_e} - \frac{T_p - T_w}{(h_1 \Delta \theta^1)_w} \right] \text{ if } G_e > 0 \\ &= \frac{(h_1 \Delta \theta^1)_e^2}{(h_1 \Delta \theta^1)_{i+1}} \left[\frac{T_{EE} - T_E}{(h_1 \Delta \theta^1)_{ee}} - \frac{T_E - T_p}{(h_1 \Delta \theta^1)_e} \right] \text{ if } G_e < 0 \end{aligned} \quad (3.31)$$

and

$$\begin{aligned} (h_1 \Delta \theta^1)_e &= \frac{1}{2} [(h_1 \Delta \theta^1)_i + (h_1 \Delta \theta^1)_{i+1}] \\ (h_1 \Delta \theta^1)_w &= \frac{1}{2} [(h_1 \Delta \theta^1)_i + (h_1 \Delta \theta^1)_{i-1}] \\ (h_1 \Delta \theta^1)_{ee} &= \frac{1}{2} [(h_1 \Delta \theta^1)_{i+1} + (h_1 \Delta \theta^1)_{i+2}] \\ (h_1 \Delta \theta^1)_{ww} &= \frac{1}{2} [(h_1 \Delta \theta^1)_{i-1} + (h_1 \Delta \theta^1)_{i-2}] \end{aligned} \quad (3.32)$$

Equation (3.22) now becomes:

$$\begin{aligned} & [(\rho C_{pm} T)^n - (\rho C_{pm} T)^{n-1}] h_1 \frac{\Delta V}{\Delta \xi} \\ &= A_E T_E + A_w T_w - A_p T_p + S (h_1 \Delta \theta^1) \end{aligned} \quad (3.33)$$

T_{ee} and T_{ww} are included in the source term using a semi-implicit tri-diagonal solution procedure. For a uniform grid, the other coefficients are:

$$A_E = \frac{C_{pm_e} (-7G_e + 3|G_e|)}{16} + C_{pm_v} (-G_v + |G_v|) + \frac{k_e}{h_1 \Delta \theta^1} \quad (3.34)$$

$$A_N = \frac{C_{pm_v} (9G_v + 3|G_v|)}{16} + C_{pm_e} (G_e + |G_e|) + \frac{k_v}{h_1 \Delta \theta^1} \quad (3.35)$$

$$A_p = \frac{9}{16} (G_v C_{pm_e} - G_e C_{pm_v}) + 3 (|G_v| C_{pm_e} + G_e) + \frac{k_v + k_e}{h_1 \Delta \theta^1} \quad (3.36)$$

$$S_p = Sh_1 \Delta \theta^1 - C_{pm_e} (|G_e| - G_e) T_{EE} - C_{pm_v} (|G_v| + G_v) T_{WW} \quad (3.37)$$

As mentioned before, Yang [Ref. 12:pp. 82-89] extended the QUICK algorithm to three dimensions. The three dimensional algorithm for generalized orthogonal coordinate system is described below.

As in the one dimensional case, the average temperature of the control volume is determined by interpolation of its neighbors in three directions. For illustration, Figure 3.6 from Raycraft [Ref. 29:pp. 68] shows a simpler uniform rectangular grid. The actual grid is similar except that its cylindrical/spherical geometry is more difficult to show. Yang [Ref. 12] describes how curvature terms are calculated for each of the temperatures and substituted into the convection

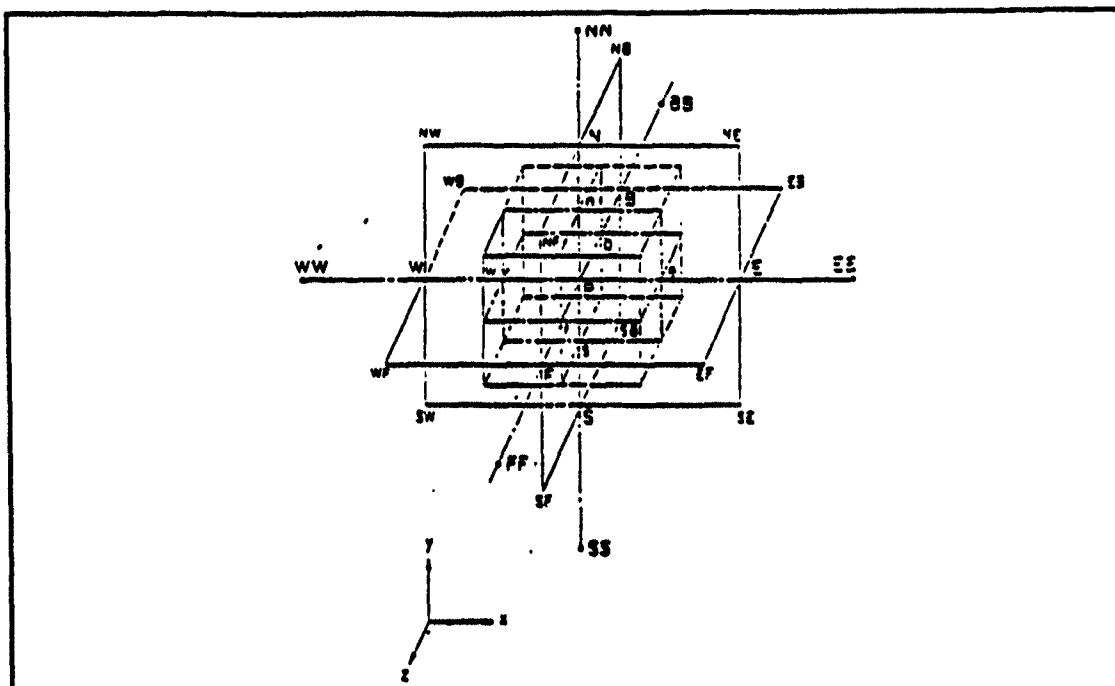


Figure 3.6 Calculation Cells for a Uniform Rectangular Grid.

terms of the energy equation. The new energy equation becomes

$$\begin{aligned}
 & [A_p^T + (\rho C_{pm})^{n-1}] \frac{\Delta V}{\Delta t} T_p \\
 & = A_E^T T_E + A_N^T T_N + A_S^T T_S + A_F^T T_F + A_B^T T_B + S_u^T
 \end{aligned}
 \tag{3.38}$$

where the additional source term S_u^T is:

$$S_u^T = (\rho C_{pm})^{n-1} \frac{\Delta V}{\Delta t} - A_{EER} + A_{NNR} + A_{SSR} + A_{FFR} + A_{BBR}
 \tag{3.39}$$

The following terms are part of Equation (3.38). All values are for point (i, j, k) unless specified elsewhere. For = =

example, $u_{1,j,k}^1$ is designated u_1^1 whereas, $u_{i+1,j,k}$ is specified u_{i+1} .

$$\begin{aligned}
 CN &= G_n \cdot u_{j+1}^2 \cdot (h_3 \Delta \theta^3)_n \cdot (h_1 \Delta \theta^1)_n \\
 CS &= G_s \cdot u_j^2 \cdot (h_3 \Delta \theta^3)_s \cdot (h_1 \Delta \theta^1)_s \\
 CE &= G_e \cdot u_{i+1}^1 \cdot (h_3 \Delta \theta^3)_e \cdot (h_2 \Delta \theta^2)_e \\
 CW &= G_w \cdot u_i^1 \cdot (h_3 \Delta \theta^3)_w \cdot (h_2 \Delta \theta^2)_w \\
 CF &= G_f \cdot u_{k+1}^3 \cdot (h_1 \Delta \theta^1)_f \cdot (h_2 \Delta \theta^2)_f \\
 CB &= G_b \cdot u_k^3 \cdot (h_1 \Delta \theta^1)_b \cdot (h_2 \Delta \theta^2)_b
 \end{aligned} \tag{3.40}$$

Thermal conductivity is expressed as:

$$\begin{aligned}
 k_n &= \left[\frac{(k_j \cdot (h_2 \Delta \theta^2)_j)^{-1} + (k_{j+1} \cdot (h_2 \Delta \theta^2)_{j+1})^{-1}}{(h_2 \Delta \theta^2)_j + (h_2 \Delta \theta^2)_{j+1}} \right]^{-1} \\
 k_s &= \left[\frac{(k_j \cdot (h_2 \Delta \theta^2)_j)^{-1} + (k_{j-1} \cdot (h_2 \Delta \theta^2)_{j-1})^{-1}}{(h_2 \Delta \theta^2)_j + (h_2 \Delta \theta^2)_{j-1}} \right]^{-1} \\
 k_e &= \left[\frac{(k_i \cdot (h_1 \Delta \theta^1)_i)^{-1} + (k_{i+1} \cdot (h_1 \Delta \theta^1)_{i+1})^{-1}}{(h_1 \Delta \theta^1)_i + (h_1 \Delta \theta^1)_{i+1}} \right]^{-1} \\
 k_w &= \left[\frac{(k_i \cdot (h_1 \Delta \theta^1)_i)^{-1} + (k_{i-1} \cdot (h_1 \Delta \theta^1)_{i-1})^{-1}}{(h_1 \Delta \theta^1)_i + (h_1 \Delta \theta^1)_{i-1}} \right]^{-1} \\
 k_f &= \left[\frac{(k_k \cdot (h_3 \Delta \theta^3)_k)^{-1} + (k_{k+1} \cdot (h_3 \Delta \theta^3)_{k+1})^{-1}}{(h_3 \Delta \theta^3)_k + (h_3 \Delta \theta^3)_{k+1}} \right]^{-1} \\
 k_b &= \left[\frac{(k_k \cdot (h_3 \Delta \theta^3)_k)^{-1} + (k_{k-1} \cdot (h_3 \Delta \theta^3)_{k-1})^{-1}}{(h_3 \Delta \theta^3)_k + (h_3 \Delta \theta^3)_{k-1}} \right]^{-1}
 \end{aligned} \tag{3.41}$$

$$CONDN1 = k_n \cdot \left[\frac{h_3 \Delta \theta^3 \cdot h_1 \Delta \theta^1}{h_2 \Delta \theta^2} \right]_n$$

$$CONDS1 = k_s \cdot \left[\frac{h_3 \Delta \theta^3 \cdot h_1 \Delta \theta^1}{h_2 \Delta \theta^2} \right]_s$$

$$CONDE1 = k_e \cdot \left[\frac{h_3 \Delta \theta^3 \cdot h_2 \Delta \theta^2}{h_1 \Delta \theta^1} \right]_e$$

$$CONDW1 = k_w \cdot \left[\frac{h_3 \Delta \theta^3 \cdot h_2 \Delta \theta^2}{h_1 \Delta \theta^1} \right]_w$$

$$CONDF1 = k_f \cdot \left[\frac{h_1 \Delta \theta^1 \cdot h_2 \Delta \theta^2}{h_3 \Delta \theta^3} \right]_f$$

$$CONDB1 = k_b \cdot \left[\frac{h_1 \Delta \theta^1 \cdot h_2 \Delta \theta^2}{h_3 \Delta \theta^3} \right]_b$$

(3.42)

$$CEP = \frac{|CE| + CE}{16} \cdot \frac{(h_1 \Delta \theta^1)_e}{(h_1 \Delta \theta^1)_i}$$

$$CEM = \frac{|CE| - CE}{16} \cdot \frac{(h_1 \Delta \theta^1)_e}{(h_1 \Delta \theta^1)_{i+1}}$$

$$CWP = \frac{|CW| + CW}{16} \cdot \frac{(h_1 \Delta \theta^1)_w}{(h_1 \Delta \theta^1)_{i-1}}$$

$$CWM = \frac{|CW| - CW}{16} \cdot \frac{(h_1 \Delta \theta^1)_w}{(h_1 \Delta \theta^1)_i}$$

$$CNP = \frac{|CN| + CN}{16} \cdot \frac{(h_2 \Delta \theta^2)_n}{(h_2 \Delta \theta^2)_j}$$

$$CNM = \frac{|CN| - CN}{16} \cdot \frac{(h_2 \Delta \theta^2)_n}{(h_2 \Delta \theta^2)_{j+1}}$$

$$CSP = \frac{|CS| + CS}{16} \cdot \frac{(h_2 \Delta \theta^2)_s}{(h_2 \Delta \theta^2)_{j-1}}$$

$$CSM = \frac{|CS| - CS}{16} \cdot \frac{(h_2 \Delta \theta^2)_s}{(h_2 \Delta \theta^2)_j}$$

$$CFP = \frac{|CF| + CF}{16} \cdot \frac{(h_3 \Delta \theta^3)_f}{(h_3 \Delta \theta^3)_k}$$

$$CFM = \frac{|CF| - CF}{16} \cdot \frac{(h_3 \Delta \theta^3)_f}{(h_3 \Delta \theta^3)_{k+1}}$$

$$CBP = \frac{|CB| + CB}{16} \cdot \frac{(h_3 \Delta \theta^3)_b}{(h_3 \Delta \theta^3)_{k-1}}$$

$$CBM = \frac{|CB| - CB}{16} \cdot \frac{(h_3 \Delta \theta^3)_b}{(h_3 \Delta \theta^3)_k}$$

(3.43)

$$\begin{aligned}
A_{EE}^T &= \frac{-CEM \cdot (h_1 \Delta \theta^1)_e}{(h_1 \Delta \theta^1)_{ee}} \\
A_{NN}^T &= \frac{-CWP \cdot (h_1 \Delta \theta^1)_w}{(h_1 \Delta \theta^1)_{ww}} \\
A_{NN}^T &= \frac{-CNM \cdot (h_2 \Delta \theta^2)_n}{(h_2 \Delta \theta^2)_{nn}} \\
A_{SS}^T &= \frac{-CSP \cdot (h_2 \Delta \theta^2)_s}{(h_2 \Delta \theta^2)_{ss}} \\
A_{FF}^T &= \frac{-CFM \cdot (h_3 \Delta \theta^3)_f}{(h_3 \Delta \theta^3)_{ff}} \\
A_{BB}^T &= \frac{-CBP \cdot (h_3 \Delta \theta^3)_b}{(h_3 \Delta \theta^3)_{bb}}
\end{aligned} \tag{3.44}$$

Final coefficients for the source term are:

$$\begin{aligned}
A_{EEr} &= A_{EE}^T \cdot T_{1+2} \cdot C_{pm_{1+2}} \\
A_{NNr} &= A_{NN}^T \cdot T_{1-2} \cdot C_{pm_{1-2}} \\
A_{NNR} &= A_{NN}^T \cdot T_{j+2} \cdot C_{pm_{j+2}} \\
A_{SSr} &= A_{SS}^T \cdot T_{j-2} \cdot C_{pm_{j-2}} \\
A_{FFr} &= A_{FF}^T \cdot T_{k+2} \cdot C_{pm_{k+2}} \\
A_{BBR} &= A_{BB}^T \cdot T_{k-2} \cdot C_{pm_{k-2}}
\end{aligned} \tag{3.45}$$

Intermediate coefficients are:

$$A_{EI} = -\frac{1}{2} \cdot CE + CEP + CEM$$

$$\cdot \left[1 + \frac{(h_1 \Delta \theta^1)_e}{(h_1 \Delta \theta^1)_{ee}} \right] + CWM \cdot \left[\frac{(h_1 \Delta \theta^1)_w}{(h_1 \Delta \theta^1)_e} \right] \quad (3.46)$$

$$A_{NI} = \frac{1}{2} \cdot CW + CWM + CWP$$

$$\cdot \left[1 + \frac{(h_1 \Delta \theta^1)_w}{(h_1 \Delta \theta^1)_{ww}} \right] + CEP \cdot \left[\frac{(h_1 \Delta \theta^1)_e}{(h_1 \Delta \theta^1)_w} \right] \quad (3.47)$$

$$A_{NI} = -\frac{1}{2} \cdot CN + CNP + CNM$$

$$\cdot \left[1 + \frac{(h_2 \Delta \theta^2)_n}{(h_2 \Delta \theta^2)_{nn}} \right] + CEP \cdot \left[\frac{(h_2 \Delta \theta^2)_e}{(h_2 \Delta \theta^2)_n} \right] \quad (3.48)$$

$$A_{SI} = \frac{1}{2} \cdot CS + CSM + CSP$$

$$\cdot \left[1 + \frac{(h_2 \Delta \theta^2)_s}{(h_2 \Delta \theta^2)_{ss}} \right] + CNP \cdot \left[\frac{(h_2 \Delta \theta^2)_n}{(h_2 \Delta \theta^2)_s} \right] \quad (3.49)$$

$$A_{FI} = -\frac{1}{2} \cdot CF + CFP + CFM$$

$$\cdot \left[1 + \frac{(h_3 \Delta \theta^3)_f}{(h_3 \Delta \theta^3)_{ff}} \right] + CBM \cdot \left[\frac{(h_3 \Delta \theta^3)_b}{(h_3 \Delta \theta^3)_f} \right] \quad (3.50)$$

$$A_{SI} = \frac{1}{2} \cdot CB + CBM + CBP$$

$$\cdot \left[1 + \frac{(h_3 \Delta \theta^3)_b}{(h_3 \Delta \theta^3)_{bb}} \right] + CFP \cdot \left[\frac{(h_3 \Delta \theta^3)_f}{(h_3 \Delta \theta^3)_b} \right] \quad (3.51)$$

Final coefficients are:

$$\begin{aligned}
 A_E^T &= A_{EI} \cdot C_{pm} + CONDE1 \\
 A_N^T &= A_{NI} \cdot C_{pm} + CONDW1 \\
 A_N^T &= A_{NI} \cdot C_{pm} + CONDN1 \\
 A_S^T &= A_{SI} \cdot C_{pm} + CONDS1 \\
 A_F^T &= A_{FI} \cdot C_{pm} + CONDF1 \\
 A_B^T &= A_{BI} \cdot C_{pm} + CONDB1
 \end{aligned} \tag{3.52}$$

and:

$$\begin{aligned}
 A_p^T &= C_{pm} \cdot (A_E^T + A_N^T + A_N^T + A_S^T + A_F^T + A_B^T \\
 &+ A_{EE}^T + A_{NN}^T + A_{NN}^T + A_{SS}^T + A_{FF}^T + A_{BB}^T) + CONDE1 \\
 &+ CONDW1 + CONDN1 + CONDS1 + CONDF1 + CONDB1
 \end{aligned} \tag{3.53}$$

F. DISCRETIZATION OF THE MOMENTUM EQUATION

The integrated momentum equation is:

$$\begin{aligned}
 (\rho u^1)_t V + M_e^{11} A_e - M_w^{11} A_w + M_n^{12} A_n \\
 - M_s^{12} A_s + M_f^{13} A_f - M_b^{13} A_b = S^1
 \end{aligned} \tag{3.54}$$

where A_i are the face areas of the staggered cell given by Equations (3.14 - 3.16). M^{ij} is the momentum flux in the θ^{ij} direction due to velocity u^i convection and to diffusion, and is given by:

$$M^{ij} = (\rho u^i u^j - \sigma_i^j) \tag{3.55}$$

Included in the source term S^i are pressure gradient, body, coriolis and centrifugal forces. The source term for velocity u^i is:

$$S^i = -P_e A_e + P_w A_w + \rho G^i \Delta V - M_p^{12} (A_n - A_s) - M_p^{13} (A_r - A_b) + (M_p^{22} + M_p^{33}) (A_e + A_w) \quad (3.56)$$

Yang, et al. [Ref. 19:pp. 11-13] describe a "stress flux formation" as it applies to a curvilinear coordinate system. Stresses are evaluated from previous information and the source is given in the current information. The momentum flux is:

$$M^{ij} = \hat{M}^{ij} + (\sigma_i^j - \sigma_j^i) \quad (3.57)$$

where:

$$\sigma_i^j = \frac{\mu}{\left[h_j \left(\frac{\partial u^i}{\partial \theta^j} \right) \right]} \quad (3.58)$$

$$\hat{M}^{ij} = \rho u^i u^j - \sigma_i^j \quad (3.59)$$

The momentum equation for velocity u^i is now:

$$(\rho u)_e + \hat{M}_e^{11} A_e - \hat{M}_w^{11} A_w + \hat{M}_n^{12} A_n - \hat{M}_s^{12} A_s + \hat{M}_r^{13} A_r + \hat{M}_b^{13} A_b = \hat{S} \quad (3.60)$$

where:

$$\begin{aligned} \hat{S} = S - (\sigma_1^1 - \sigma_1^1)_e A_e + (\sigma_1^1 - \sigma_1^1)_w A_w - (\sigma_1^2 - \sigma_1^2)_n A_n \\ + (\sigma_1^2 - \sigma_1^2)_s A_s - (\sigma_1^3 - \sigma_1^3)_r A_r - (\sigma_1^3 - \sigma_1^3)_b A_b \end{aligned} \quad (3.61)$$

The momentum equation for θ^1 takes a form similar to the energy equation

$$\left(A_p^{u^1} + \rho^{n-1} \frac{\Delta V}{\Delta E} \right) u_p^2 = A_s^{u^1} u_s^1 + A_w^{u^1} u_w^1 + A_n^{u^1} u_n^1 + A_s^{u^1} u_s^1 + A_f^{u^1} u_f^1 + A_b^{u^1} u_b^1 + S^{u^1} u^1 \quad (3.62)$$

Again we must obtain final coefficients. Introducing intermediate mass flow rate per unit area:

$$\begin{aligned} G_{ne} &= u_{j+1}^2 \left\{ \frac{[\rho_{j+1} (h_2 \Delta \theta^2)_j + \rho_j (h_2 \Delta \theta^2)_{j+1}]}{(h_2 \Delta \theta^2)_j + (h_2 \Delta \theta^2)_{j+1}} \right\} \\ G_{nw} &= u_{i-1, j+1}^2 \left\{ \frac{[\rho_{i-1, j+1} (h_2 \Delta \theta^2)_j + \rho_{i-1} (h_2 \Delta \theta^2)_{j+1}]}{(h_2 \Delta \theta^2)_j + (h_2 \Delta \theta^2)_{j+1}} \right\} \\ G_{se} &= u^2 \left\{ \frac{[\rho_{j-1} (h_2 \Delta \theta^2)_j + \rho_j (h_2 \Delta \theta^2)_{j-1}]}{(h_2 \Delta \theta^2)_j + (h_2 \Delta \theta^2)_{j-1}} \right\} \\ G_{sw} &= u_{i-1}^2 \left\{ \frac{[\rho_{i-1, j-1} (h_2 \Delta \theta^2)_j + \rho_{i-1} (h_2 \Delta \theta^2)_{j-1}]}{(h_2 \Delta \theta^2)_j + (h_2 \Delta \theta^2)_{j-1}} \right\} \\ G_e &= u_{i+1}^1 \left\{ \frac{[\rho_{i+1} (h_1 \Delta \theta^1)_e + \rho_i (h_1 \Delta \theta^1)_{ee}]}{(h_1 \Delta \theta^1)_e + (h_1 \Delta \theta^1)_{ee}} \right\} \end{aligned} \quad (3.63a)$$

$$\begin{aligned}
G_p &= u \cdot \left\{ \frac{[\rho_{i-1} (h_1 \Delta \theta^1)_e + \rho_i (h_1 \Delta \theta^1)_w]}{(h_1 \Delta \theta^1)_e + h_1 \Delta \theta^1_w} \right\} \\
G_w &= u_{i-1}^1 \left\{ \frac{[\rho_{i-2} (h_1 \Delta \theta^1)_w + \rho_{i-1} (h_1 \Delta \theta^1)_{ww}]}{(h_1 \Delta \theta^1)_w + (h_1 \Delta \theta^1)_{ww}} \right\} \\
G_{fe} &= u_{k+1}^3 \left\{ \frac{[\rho_{k+1} (h_3 \Delta \theta^3)_k + \rho_k (h_3 \Delta \theta^3)_{k+1}]}{(h_3 \Delta \theta^3)_k + (h_3 \Delta \theta^3)_{k+1}} \right\} \\
G_{fw} &= u_{i-1, k+1}^3 \left\{ \frac{[\rho_{i-1, k+1} (h_3 \Delta \theta^3)_k + \rho_{i-1} (h_3 \Delta \theta^3)_{k+1}]}{(h_3 \Delta \theta^3)_k + (h_3 \Delta \theta^3)_{k+1}} \right\} \\
G_{be} &= u^3 \left\{ \frac{[\rho_{k-1} (h_3 \Delta \theta^3)_k + \rho_k (h_3 \Delta \theta^3)_{k-1}]}{(h_3 \Delta \theta^3)_k + (h_3 \Delta \theta^3)_{k-1}} \right\} \\
G_{bw} &= u_{i-1}^3 \left\{ \frac{[\rho_{i-1, k-1} (h_3 \Delta \theta^3)_k + \rho_{i-1} (h_3 \Delta \theta^3)_{k-1}]}{(h_3 \Delta \theta^3)_k + (h_3 \Delta \theta^3)_{k-1}} \right\}
\end{aligned} \tag{3.63b}$$

Final mass flow rates are:

$$\begin{aligned}
CE &= \frac{1}{2} (G_e + G_p) \cdot (h_2 \Delta \theta^2)_e \cdot (h_3 \Delta \theta^3)_e \\
CW &= \frac{1}{2} (G_p + G_w) \cdot (h_2 \Delta \theta^2)_w \cdot (h_3 \Delta \theta^3)_w \\
CN &= (h_1 \Delta \theta^1)_n \cdot (h_3 \Delta \theta^3)_n \cdot \left\{ \frac{[G_{ne} (h_1 \Delta \theta^1)_w + G_{nw} (h_1 \Delta \theta^1)_e]}{(h_1 \Delta \theta^1)_w + (h_1 \Delta \theta^1)_e} \right\} \\
CS &= (h_1 \Delta \theta^1)_s \cdot (h_3 \Delta \theta^3)_s \cdot \left\{ \frac{[G_{se} (h_1 \Delta \theta^1)_w + G_{sw} (h_1 \Delta \theta^1)_e]}{(h_1 \Delta \theta^1)_w + (h_1 \Delta \theta^1)_e} \right\} \\
CF &= (h_1 \Delta \theta^1)_f \cdot (h_2 \Delta \theta^2)_f \cdot \left\{ \frac{[G_{fe} (h_1 \Delta \theta^1)_w + G_{fw} (h_1 \Delta \theta^1)_e]}{(h_1 \Delta \theta^1)_w + (h_1 \Delta \theta^1)_e} \right\} \\
CB &= (h_1 \Delta \theta^1)_b \cdot (h_2 \Delta \theta^2)_b \cdot \left\{ \frac{[G_{be} (h_1 \Delta \theta^1)_w + G_{bw} (h_1 \Delta \theta^1)_e]}{(h_1 \Delta \theta^1)_w + (h_1 \Delta \theta^1)_e} \right\}
\end{aligned} \tag{3.64}$$

The local viscosity is:

$$\begin{aligned}
 VIS_n &= VIS \\
 VIS_w &= VIS_{i-1} \\
 VIS_n &= \frac{(VIS_{j+1} + VIS + VIS_{i-1, j+1} + VIS_{i-1})}{4} \\
 VIS_s &= \frac{(VIS_{j-1} + VIS + VIS_{i-1, j-1} + VIS_{i-1})}{4} \\
 VIS_f &= \frac{(VIS_{k+1} + VIS + VIS_{i-1, k+1} + VIS_{i-1})}{4} \\
 VIS_b &= \frac{(VIS_{k-1} + VIS + VIS_{i-1, k-1} + VIS_{i-1})}{4}
 \end{aligned} \tag{3.65}$$

$$\begin{aligned}
 VISN1 &= VIS_n \cdot \left[\frac{(h_3 \Delta \theta^3) (h_1 \Delta \theta^1)}{(h_2 \Delta \theta^2)} \right]_n \\
 VISS1 &= VIS_s \cdot \left[\frac{(h_3 \Delta \theta^3) (h_1 \Delta \theta^1)}{(h_2 \Delta \theta^2)} \right]_s \\
 VISE1 &= VIS_e \cdot \left[\frac{(h_2 \Delta \theta^2) (h_3 \Delta \theta^3)}{(h_1 \Delta \theta^1)} \right]_e \\
 VISW1 &= VIS_w \cdot \left[\frac{(h_2 \Delta \theta^2) (h_3 \Delta \theta^3)}{(h_1 \Delta \theta^1)} \right]_w \\
 VISF1 &= VIS_f \cdot \left[\frac{(h_1 \Delta \theta^1) (h_2 \Delta \theta^2)}{(h_3 \Delta \theta^3)} \right]_f \\
 VISB1 &= VIS_b \cdot \left[\frac{(h_1 \Delta \theta^1) (h_2 \Delta \theta^2)}{(h_3 \Delta \theta^3)} \right]_b
 \end{aligned} \tag{3.66}$$

The momentum equation coefficients are:

$$\begin{aligned}
 A_{EER} &= A_{EE}^u \cdot u_{i+1}^1 \\
 A_{NWR} &= A_{NW}^u \cdot u_{i-2}^1 \\
 A_{NNR} &= A_{NN}^u \cdot u_{j+2}^1 \\
 A_{SSR} &= A_{SS}^u \cdot u_{j-2}^1 \\
 A_{FTT} &= A_{FT}^u \cdot u_{k+2}^1 \\
 A_{SSR} &= A_{SS}^u \cdot u_{k-2}^1
 \end{aligned}
 \tag{3.67}$$

As with the energy equation, the value of the final coefficients are:

$$\begin{aligned}
 A_E^u &= A_{EI} + VISE1 \\
 A_N^u &= A_{NI} + VISN1 \\
 A_N^u &= A_{NI} + VISN1 \\
 A_S^u &= A_{SI} + VISS1 \\
 A_F^u &= A_{FI} + VISF1 \\
 A_S^u &= A_{SI} + VISB1
 \end{aligned}
 \tag{3.68}$$

and

$$\begin{aligned}
 A_p^u &= A_E^u + A_N^u + A_N^u + A_S^u + A_F^u + A_S^u \\
 &+ A_{EE}^u + A_{NW}^u + A_{NN}^u + A_{SS}^u + A_{FT}^u + A_{SS}^u
 \end{aligned}
 \tag{3.69}$$

The final source term is given as

$$\begin{aligned}
 S_u^u = & \frac{[\rho (h_1 \Delta \theta^1)_w + \rho_{i-1} (h_1 \Delta \theta^1)_e]}{[(h_1 \Delta \theta^1)_w + (h_1 \Delta \theta^1)_e]} \cdot \frac{\Delta V}{\Delta t} \cdot u^1 \\
 & + (h_2 \Delta \theta^2)_j (h_3 \Delta \theta^3)_k (P_{i-1} - P_i) + A_{EER} + A_{NNR} + A_{NNR} \\
 & + A_{SSR} + A_{FTR} + A_{BBR} + RE - RW + N - RS \\
 & + RF - RB + RRY + RRZ - RRY \cdot BUOY \\
 & \cdot \{ \sin [ZC(K)] \cdot (\rho - \rho_{eq}) \cdot (h_1 \Delta \theta^1)_w \\
 & \cdot \cos [XC(I)] \} + \{ (\rho_{i-1} - \rho_{eq_{i-1}}) (h_1 \Delta \theta^1)_e \\
 & \cdot \cos [XC(I-1)] \} / [(h_1 \Delta \theta^1)_w + (h_1 \Delta \theta^1)_e] \Delta V
 \end{aligned} \tag{3.70}$$

where XC and ZC represent the center of the cell. The remainder of the terms are explained below.

$$\begin{aligned}
 RE &= (h_2 \Delta \theta^2)_e (h_3 \Delta \theta^3)_e \cdot \left[\frac{\sigma^{11} - (u_{i+1}^1 - u_i^1) \cdot VIS_e}{(h_1 \Delta \theta^1)_e} \right] \\
 RW &= (h_2 \Delta \theta^2)_w (h_3 \Delta \theta^3)_w \cdot \left[\frac{\sigma_{i-1}^{11} - (u^1 - u_{i-1}^1) \cdot VIS_w}{(h_1 \Delta \theta^1)_w} \right] \\
 RN &= (h_1 \Delta \theta^1)_n (h_3 \Delta \theta^3)_n \cdot \left[\frac{\sigma_{j+1}^{12} - (u_{j+1}^1 - u_j^1) \cdot VIS_n}{(h_2 \Delta \theta^2)_n} \right] \\
 RS &= (h_1 \Delta \theta^1)_s (h_3 \Delta \theta^3)_s \cdot \left[\frac{\sigma^{12} - (u^1 - u_{j-1}^1) \cdot VIS_s}{(h_2 \Delta \theta^2)_s} \right] \\
 RF &= (h_1 \Delta \theta^1)_f (h_2 \Delta \theta^2)_f \cdot \left[\frac{\sigma_{k+1}^{13} - (u_{k+1}^1 - u_k^1) \cdot VIS_f}{(h_3 \Delta \theta^3)_f} \right] \\
 RB &= (h_1 \Delta \theta^1)_b (h_2 \Delta \theta^2)_b \cdot \left[\frac{\sigma^{13} - (u^1 - u_{k-1}^1) \cdot VIS_b}{(h_3 \Delta \theta^3)_b} \right]
 \end{aligned} \tag{3.71}$$

$$\begin{aligned}
\bar{\sigma}^{12} &= \frac{1}{2} (\sigma_{j+1}^{12} + \sigma_j^{12}) \\
\bar{\sigma}^{13} &= \frac{1}{2} (\sigma_{k+1}^{13} + \sigma_k^{13}) \\
\bar{\sigma}^{22} &= \frac{\sigma^{22} (h_1 \Delta \theta^1)_v + \sigma_{i-1}^{22} (h_1 \Delta \theta^1)_e}{(h_1 \Delta \theta^1)_v + (h_1 \Delta \theta^1)_e} \\
\bar{\sigma}^{33} &= \frac{\sigma^{33} (h_1 \Delta \theta^1)_v + \sigma_{i-1}^{33} (h_1 \Delta \theta^1)_e}{(h_1 \Delta \theta^1)_v + (h_1 \Delta \theta^1)_e}
\end{aligned} \tag{3.72}$$

$$\begin{aligned}
AU1 &= u^1 \\
AU2 &= \left\{ \left[\frac{u_{j+1}^2 (h_2 \Delta \theta^2)_j + u_j^2 (h_2 \Delta \theta^2)_j}{2 (h_2 \Delta \theta^2)_j} \right] (h_1 \Delta \theta^1)_v \right. \\
&\quad \left. + \left[\frac{u_{i-1, j+1}^2 (h_2 \Delta \theta^2)_j + u_{i-1}^2 (h_2 \Delta \theta^2)_j}{2 (h_2 \Delta \theta^2)_j} \right] (h_1 \Delta \theta^1)_e \right\} \\
&\quad / [(h_1 \Delta \theta^1)_v + (h_1 \Delta \theta^1)_e] \\
AU3 &= \left\{ \left[\frac{u_{k+1}^3 (h_3 \Delta \theta^3)_k + u_k^3 (h_3 \Delta \theta^3)_k}{2 (h_3 \Delta \theta^3)_k} \right] (h_1 \Delta \theta^1)_v \right. \\
&\quad \left. + \left[\frac{u_{i-1, k+1}^3 (h_3 \Delta \theta^3)_k + u_{i-1}^3 (h_3 \Delta \theta^3)_k}{2 (h_3 \Delta \theta^3)_k} \right] (h_1 \Delta \theta^1)_e \right\} \\
&\quad / [(h_1 \Delta \theta^1)_v + (h_1 \Delta \theta^1)_e]
\end{aligned} \tag{3.73}$$

$$AR = \frac{\rho (h_1 \Delta \theta^1)_v + \rho_{i-1} (h_1 \Delta \theta^1)_e}{(h_1 \Delta \theta^1)_v + (h_1 \Delta \theta^1)_e}$$

$$\begin{aligned}
ARU12 &= AR \cdot AU1 \cdot AU2 \\
ARU13 &= AR \cdot AU1 \cdot AU3 \\
ARU22 &= AR \cdot AU2 \cdot AU2 \\
ARU33 &= AR \cdot AU3 \cdot AU3
\end{aligned} \tag{3.74}$$

$$\begin{aligned}
RRY &= (\bar{\sigma}^{12} - ARU12) (h_3 \Delta \theta^3)_k [(h_1 \Delta \theta^1)_n - (h_1 \Delta \theta^1)_s] \\
RRZ &= (\bar{\sigma}^{13} - ARU13) (h_2 \Delta \theta^2)_j [(h_1 \Delta \theta^1)_f - (h_1 \Delta \theta^1)_b] \\
RRX &= (\bar{\sigma}^{22} - AUR22) (h_3 \Delta \theta^3)_k [(h_2 \Delta \theta^2)_e - (h_2 \Delta \theta^2)_w] \\
&\quad + (\bar{\sigma}^{33} - AUR33) (h_2 \Delta \theta^2)_j [(h_3 \Delta \theta^3)_e - (h_3 \Delta \theta^3)_w]
\end{aligned} \tag{3.75}$$

Similarly, momentum equations for the other two directions may be obtained but are omitted for brevity.

G. PRESSURE CORRECTION

In the finite difference scheme, energy and momentum equations are used to solve for temperature and velocities. The equation of state and continuity are used to solve for density and pressure. Doria [Ref. 35] states that pressure is only weakly coupled to the equation of state. Therefore, updated temperatures and pressures determine density in the equation of state and continuity is used to correct pressure across each cell.

As discussed earlier, a disadvantage of using primitive variables is the difficulty in calculating pressure. Two corrections must be applied. First, a global pressure correction accounts for changes in net energy of the closed system. Second, a local pressure correction accounts for pressure changes causing the velocity field.

1. Global Pressure Correction

Nicolette, et al. [Ref. 3] developed a correction scheme for a two dimensional square enclosure. Raycraft [Ref.

30] modified it to fit the geometry of Fire-1. In a constant mass and volume system, the overall pressure depends on the addition or removal of energy. In such a system, the sum of all the cells' computed density times its volume is equal to a constant total mass. At any time during a run the mass must equal the total mass at equilibrium. Summing over N cells:

$$\sum \rho_i^n (\Delta V)_i = \sum \rho_{EQ} (\Delta V) \quad (3.76)$$

where n is the nth time step and the EQ subscript indicates the equilibrium point. Assuming that air is an ideal gas, its density is a function of temperature and pressure only. The actual values of both consist of the estimate and the global correction:

$$P = P^* + P'_g \quad (3.77)$$

$$T = T^* + T'_g \quad (3.78)$$

where P* and T* are the estimates and P_g' and T_g' are the global corrections using the ideal gas law and Equation (3.76). The global pressure correction becomes

$$P'_g = \frac{\sum P_{EQ} \left(\frac{\Delta V}{T_i} - \frac{\Delta V}{T^*} \right) - \sum \left(P^* \frac{\Delta V}{T^*} \right)}{\sum \frac{\Delta V}{T^*}} \quad (3.79)$$

Mass is conserved for each cell when an accurate final pressure is obtained.

2. Local Pressure Correction

Patanker [Ref. 36:pp. 120-126] and Doria [Ref. 36:pp. 26-32] developed a procedure for obtaining the local pressure correction. As in the global correction scheme, a pressure field is estimated from the previous time step. Velocities are calculated according to this pressure distribution and the law of continuity is applied to each cell. If the residual mass term S_{mp} approaches zero, then the estimated pressure field is satisfactory. If not, a local correction is calculated and applied to the original estimate. The new pressure field is used to compute a corrected velocity field and the residual mass S_{mp} is rechecked. The process repeats itself until S_{mp} is an acceptably small value. As in the global correction, the actual local pressure is:

$$P = P^* + P' \quad (3.80)$$

where P^* is again the estimate, usually the pressure of the preceding iteration, and P' is the local correction. Putting this correction in typical finite difference form:

$$A_p P'_p = A_E P'_E + A_N P'_N + A_S P'_S + A_F P'_F + A_B P'_B - S_{mp} \Delta V \quad (3.81)$$

where:

$$\begin{aligned}
 A_E &= \frac{\rho_e \cdot [(h_2 \Delta \theta^2) (h_3 \Delta \theta^3)]_e^2}{\left[A_{p_{e1}}^{u1} + \rho_e \frac{\Delta V}{\Delta t} \right]} \\
 A_N &= \frac{\rho_w \cdot [(h_2 \Delta \theta^2) (h_3 \Delta \theta^3)]_w^2}{\left[A_p^{u1} + \rho_w \frac{\Delta V}{\Delta t} \right]} \\
 A_N &= \frac{\rho_n \cdot [(h_1 \Delta \theta^1) (h_3 \Delta \theta^3)]_n^2}{\left[A_{p_{n1}}^{u2} + \rho_n \frac{\Delta V}{\Delta t} \right]} \\
 A_s &= \frac{\rho_s \cdot [(h_1 \Delta \theta^1) (h_3 \Delta \theta^3)]_s^2}{\left[A_p^{u2} + \rho_s \frac{\Delta V}{\Delta t} \right]} \\
 A_f &= \frac{\rho_f \cdot [(h_1 \Delta \theta^1) (h_2 \Delta \theta^2)]_f^2}{\left[A_{p_{f1}}^{u3} + \rho_f \frac{\Delta V}{\Delta t} \right]} \\
 A_b &= \frac{\rho_b \cdot [(h_1 \Delta \theta^1) (h_2 \Delta \theta^2)]_b^2}{\left[A_p^{u3} + \rho_b \frac{\Delta V}{\Delta t} \right]} \\
 A_p &= A_E + A_N + A_N + A_s + A_f + A_b
 \end{aligned} \tag{3.82}$$

Corrected velocities are:

$$\begin{aligned}
 u^1 &= u^{1*} + u^{1'} \\
 u^2 &= u^{2*} + u^{2'} \\
 u^3 &= u^{3*} + u^{3'}
 \end{aligned} \tag{3.83}$$

where:

$$\begin{aligned}
 u^{1'} &= \frac{(P_p + P_v) (h_2 \Delta \theta^2) (h_3 \Delta \theta^3)}{\left(A_p^{u1} + \rho_v \frac{\Delta V}{\Delta t} \right)} \\
 u^{2'} &= \frac{(P_p + P_s) (h_1 \Delta \theta^1) (h_3 \Delta \theta^3)}{\left(A_p^{u2} + \rho_s \frac{\Delta V}{\Delta t} \right)} \\
 u^{3'} &= \frac{(P_p + P_b) (h_1 \Delta \theta^1) (h_2 \Delta \theta^2)}{\left(A_p^{u3} + \rho_b \frac{\Delta V}{\Delta t} \right)}
 \end{aligned} \tag{3.84}$$

Again S_{mp} is computed using continuity. If the residual mass is within a satisfactory range, the calculation is finished. If not, another iteration takes place.

IV. NUMERICAL PROCESS

A. INTRODUCTION

Temperature, velocity, pressure and density fields are produced by the code. Input parameters are initial conditions, fuel heat release rate, fire location, geometry and material characteristics such as fluid properties, wall properties and the external heat transfer coefficient. These are listed in Table 4.1.

TABLE 4.1 MODEL PARAMETERS

WALL CHARACTERISTICS	
Material	ASTM 285 Grade C Steel
Thickness	3/8 inch
Specific Heat	0.1 BTU/ (lbm•F)
Thermal Conductivity	25 BTU/(hr•ft•F)
Density	487 lbm/ft ³
External Heat Transfer Coefficient	15.0 BTU/(hr•ft ² •F)
FIRE CHARACTERISTICS	
Burn Rate	Function provided in program
Initial Temperature	35.6°C
Initial Pressure	1.0 ATM
Location of Fire	Center of Fire-1 23.1 ft. from each endcap 3.21 ft. from bottom

Figures 4.1 and 4.2 show the spherical/cylindrical grid used by the model. Endcaps are spherical with θ , R , and ϕ

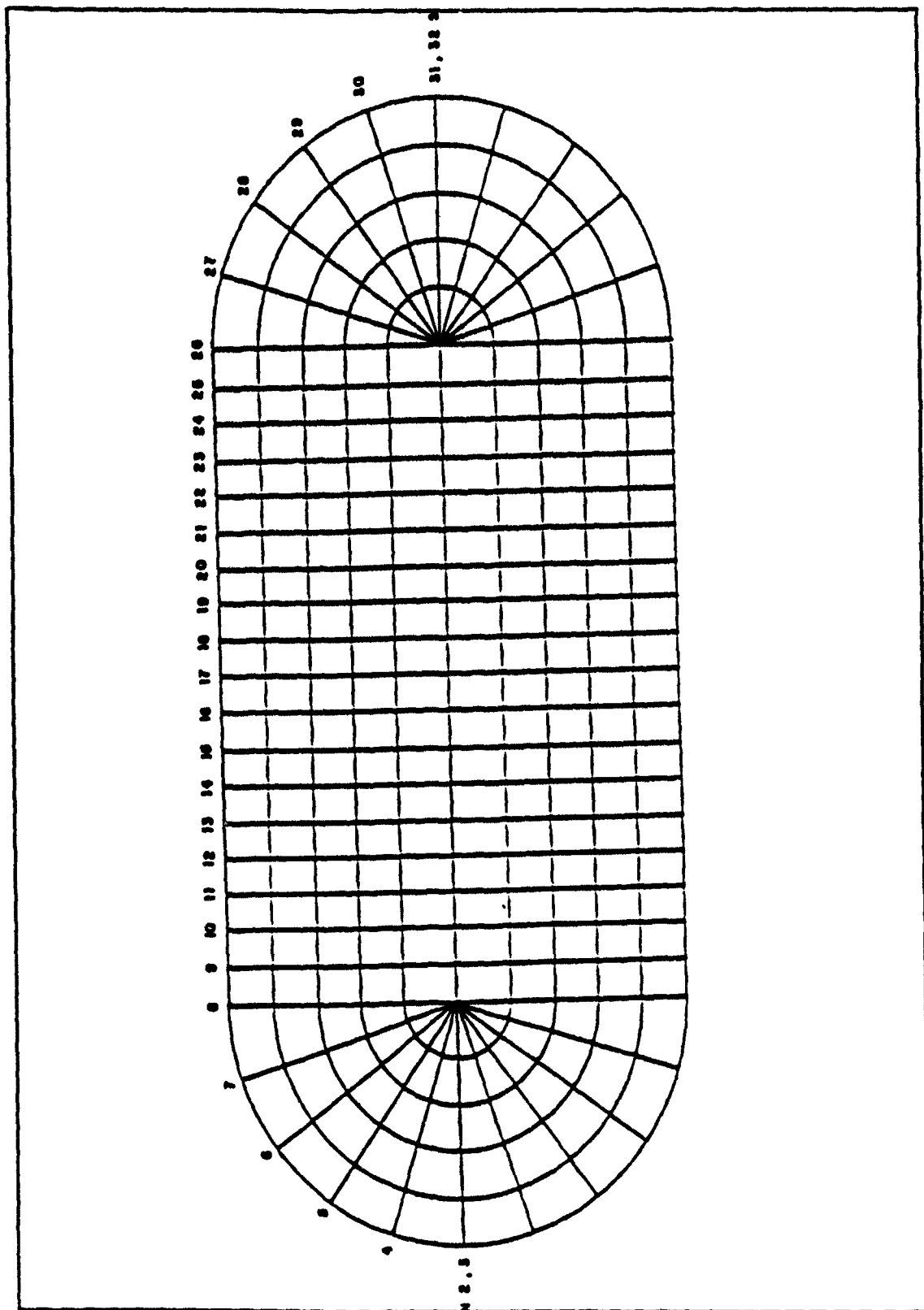


Figure 4.1 Front View of Computer Model (YZ-Plane)

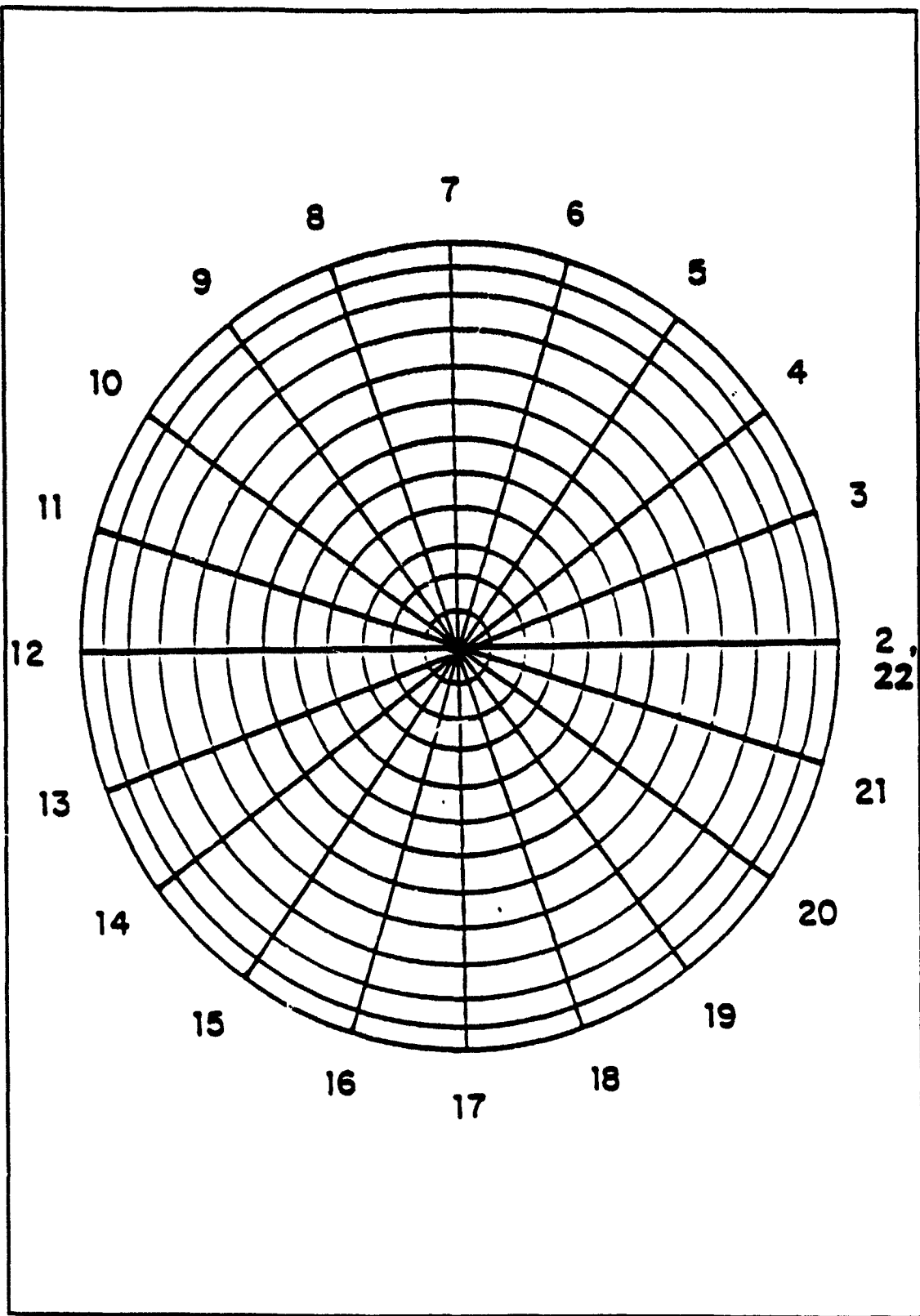


Figure 4.2 Side View of Computer Model (XY-Plane)

directions. The cylindrical midsection have θ , R and Z directions. There are 14 cells in the R direction, one at $R=0$ for avoiding singularity and one used as the vessel wall. There are 20 cells oriented clockwise in the θ direction. Each endcap has six cells in the ϕ direction with a cell again at zero to avoid singularity. The midsection has 18 cells in the Z direction (ϕ is used for simplicity). Table 4.2 gives information on grid parameters.

TABLE 4.2 ADDITIONAL MODEL PARAMETERS

GRID	
Number of interior cells	6,720
Number of wall cells	560
Number of wall radiation zones	560
Number of fire radiation zones	19
Number of cells in R direction	14
Number of cells in θ direction	20
Number of cells in ϕ direction (per endcap)	6
Number of cells in Z direction (midsection)	18
Time step	0.0288 sec
VAXSTATION 3100 CPU time (1 CPU hour)	0.8-1.0 sec
	Fire Time

B. SOLUTION PROCESS

The model contains two separate programs. The first authored by Raycraft [Ref. 29] calculates the view factors for surface radiation. It produces a matrix of view factors. It is

used only once and its values are stored for use whenever called by the second program.

As described by Nies [Ref. 27], Raycraft [Ref. 29] and Houck [Ref. 30], the main program uses finite difference methods described previously to establish temperature, velocity, pressure and density fields. Initial parameters and the view factors are first read into the program. Geometry of the grid is then calculated and the fields are set to initial conditions. Next, effective viscosity is computed in subroutine CALVIS. Every two time steps, surface radiation flux is recalculated in subroutine RADHT. Subroutines CALT, GLOBE, CALU, CALX, CALW and CALP calculate temperature, the global pressure correction, the velocities and the local pressure correction. Using the corrected velocities, continuity is applied to each cell. If the residual mass RESORM is greater than 10.0 the program is unstable and stops. A smaller time step must be used. If RESORM is greater than a set tolerance level then the program iterates solution by recalculating velocities and pressures. Iterations continue until 1) RESORM is below tolerance levels, solution is reached and the program proceeds to next time step; 2) the maximum number of iterations is reached, or 3) RESORM is greater than 10.0 and the program is stopped.

C. GRAPHICAL ANALYSIS

The use of CA-DISSPLA™ [Ref. 31] has posed some difficult problems. The output from the computer model is in the spherical/cylindrical coordinate system created to simulate Fire-1. This output must be converted to cartesian coordinates in order to be manipulated by CA-DISSPLA™. Even after the conversion is completed the resulting irregularly spaced grid must be interpolated into a regularly spaced grid.

After some experimentation with grid interpolation schemes, a group of CA-DISSPLA™ subroutines are used to create a regularly spaced matrix. These subroutines interpolate values from a set number of neighbors. Care must be taken in choosing a grid size to ensure distortion of the field values does not occur and to ensure that the software will not zero data points with few close neighbors. A relatively course grid has been chosen (50 x 50 x 100) for graphics output. New data points created outside the enclosure have been set to ambient values to minimize distortion at the boundaries.

The VAXSTATION 3100 has proven to be an excellent machine. It has good numerical speed coupled with very sharp graphics capabilities. Future research of this numerical model has been greatly enhanced by the incorporation of this workstation.

The following figures are temperature and velocity profiles for times of 30, 60, and 90 seconds. They are two dimensional images of three dimensional phenomena. Each figure, whether temperature or velocity, presents an axial view (XY-plane) of the tank at the midplane and a longitudinal view (YZ-plane), again at the midplane.

Raycraft [Ref. 29] and Houck [Ref. 30] detailed the validation of the code against experimental data of Fire-1. They also discussed such phenomena as the fire plume, pressure effect, temperature stratification, and velocity fields. Much of their analysis will not be repeated here. Instead, the effects of local numerical perturbations will be discussed.

Raycraft [Ref. 29] observed remarkable symmetry in temperature and velocity profiles throughout the entire trial. Houck [Ref. 30] also observed the expected asymmetry, after implementing forced ventilation in two locations. In this thesis, these ventilation equations are not removed. The additive velocities were simply set to zero. As seen in Figures 4.3 to 4.8, a marked asymmetry similar to that observed in Houck [Ref. 30], has developed and is readily observed in both temperature and velocity profiles. This is despite the fact that the effects of ventilation have been supposedly negated. After the millions of calculations done by the computer to provide solutions, terms in the ventilation equations which are set to zero have greatly effected the entire field.

Color graphics have greatly enhanced ability to observe phenomena in the temperature fields. Temperatures can be quickly determined using the color legend, as Figures 4.3, 4.5, and 4.7 show. These figures have been printed on a Tektronics 4693D color printer and exhibit excellent clarity and resolution.

Three dimensional vector field representation of the velocity fields, Figures 4.4, 4.6 and 4.8 can only be represented in two dimensional form for this geometry. Results become confusing if three dimensions are shown.

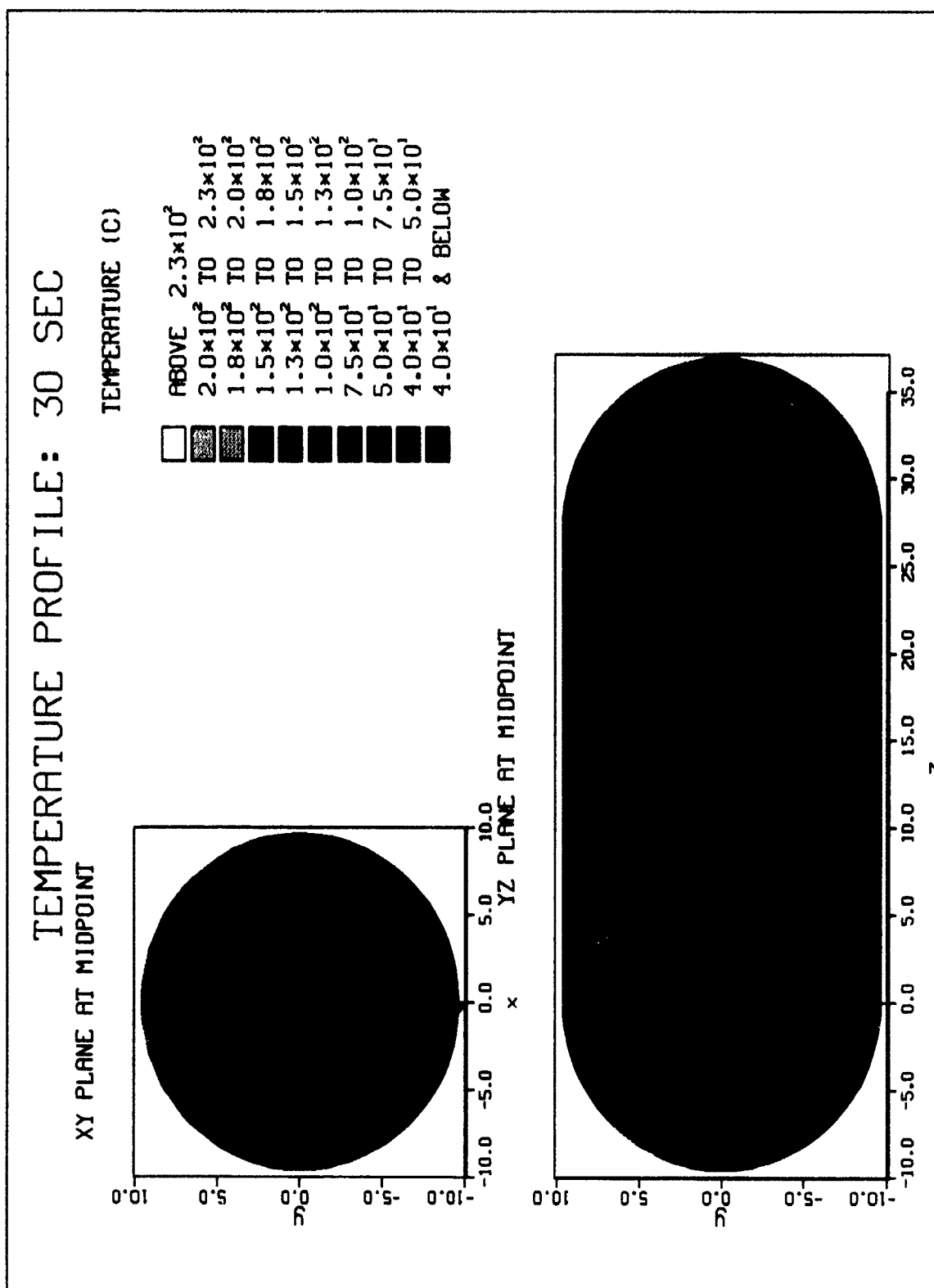


Figure 4.3 Temperature Profiles at 30 Seconds

VELOCITY PROFILE 30 SEC

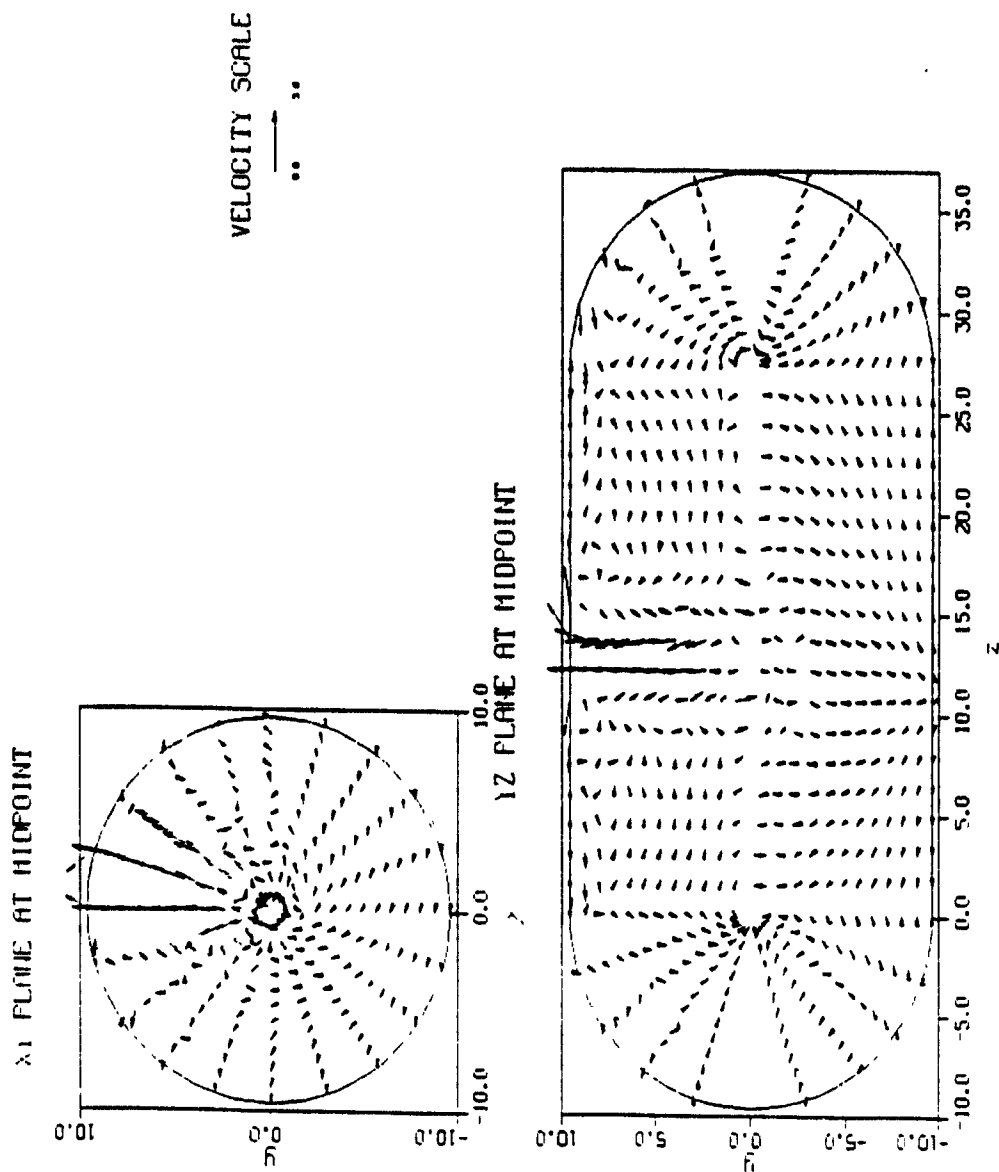


Figure 4.4 Velocity Profile at 30 Seconds

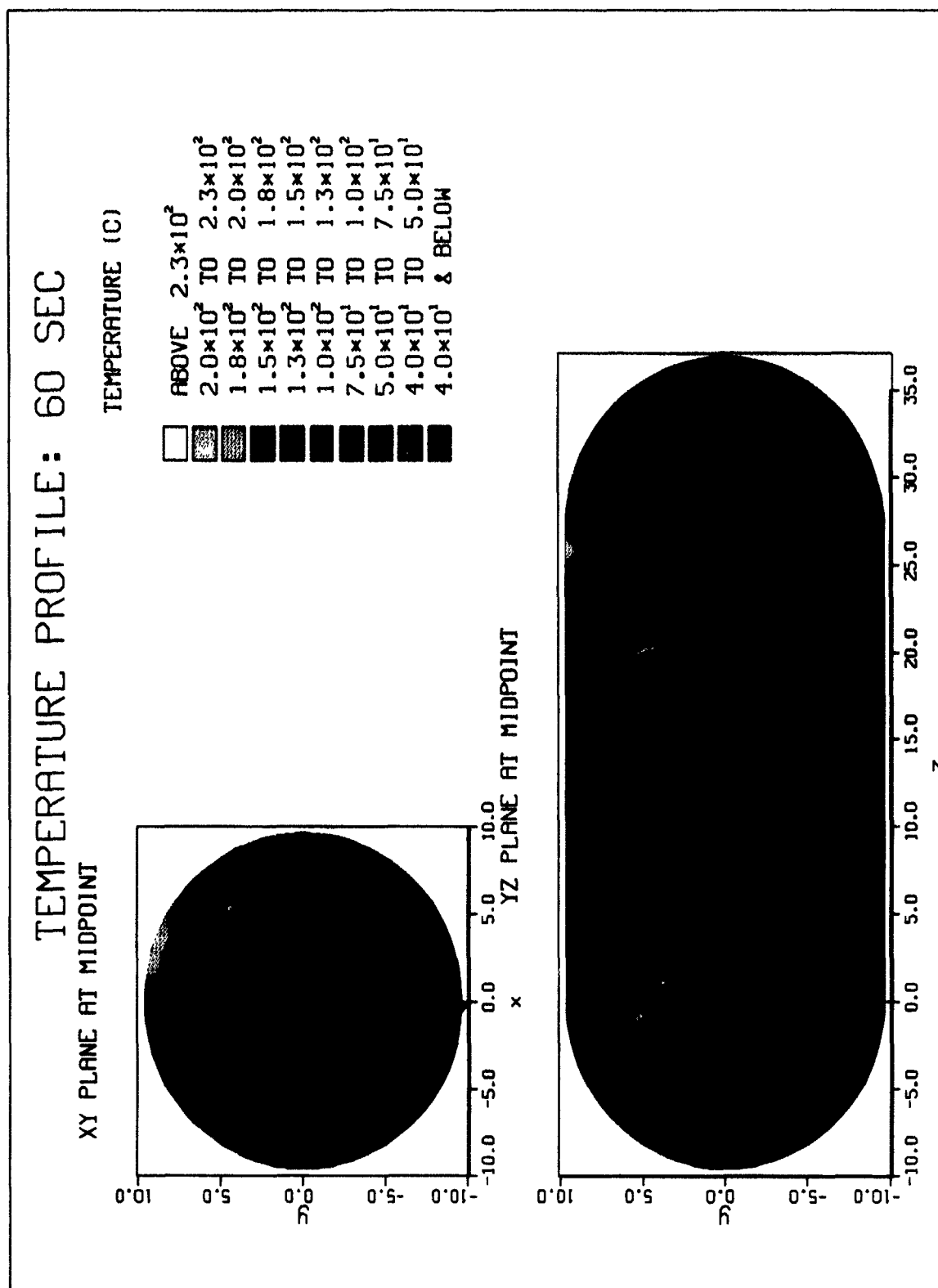


Figure 4.5 Temperature Profiles at 60 Seconds.

VELOCITY PROFILE 60 SEC

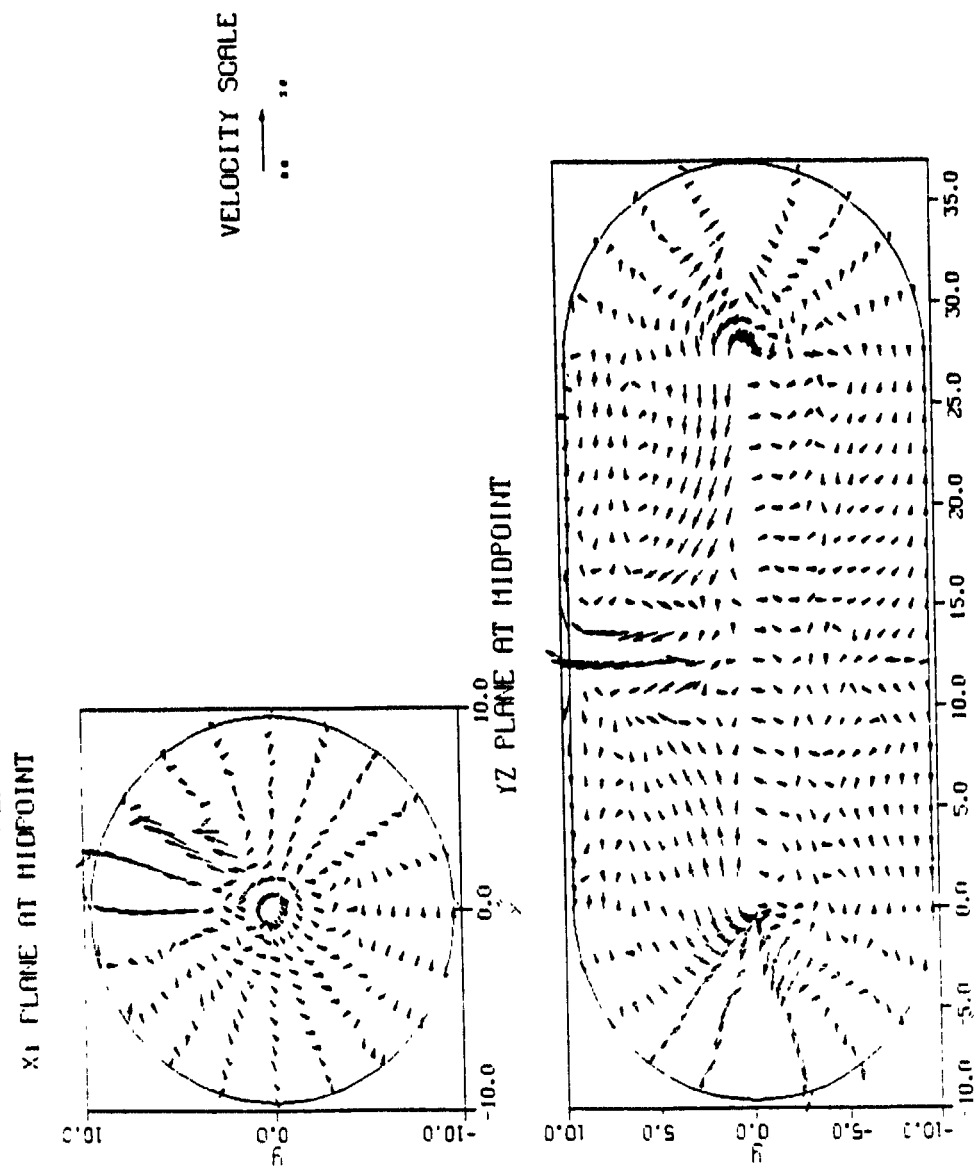


Figure 4.6 Velocity Profile at 60 Seconds

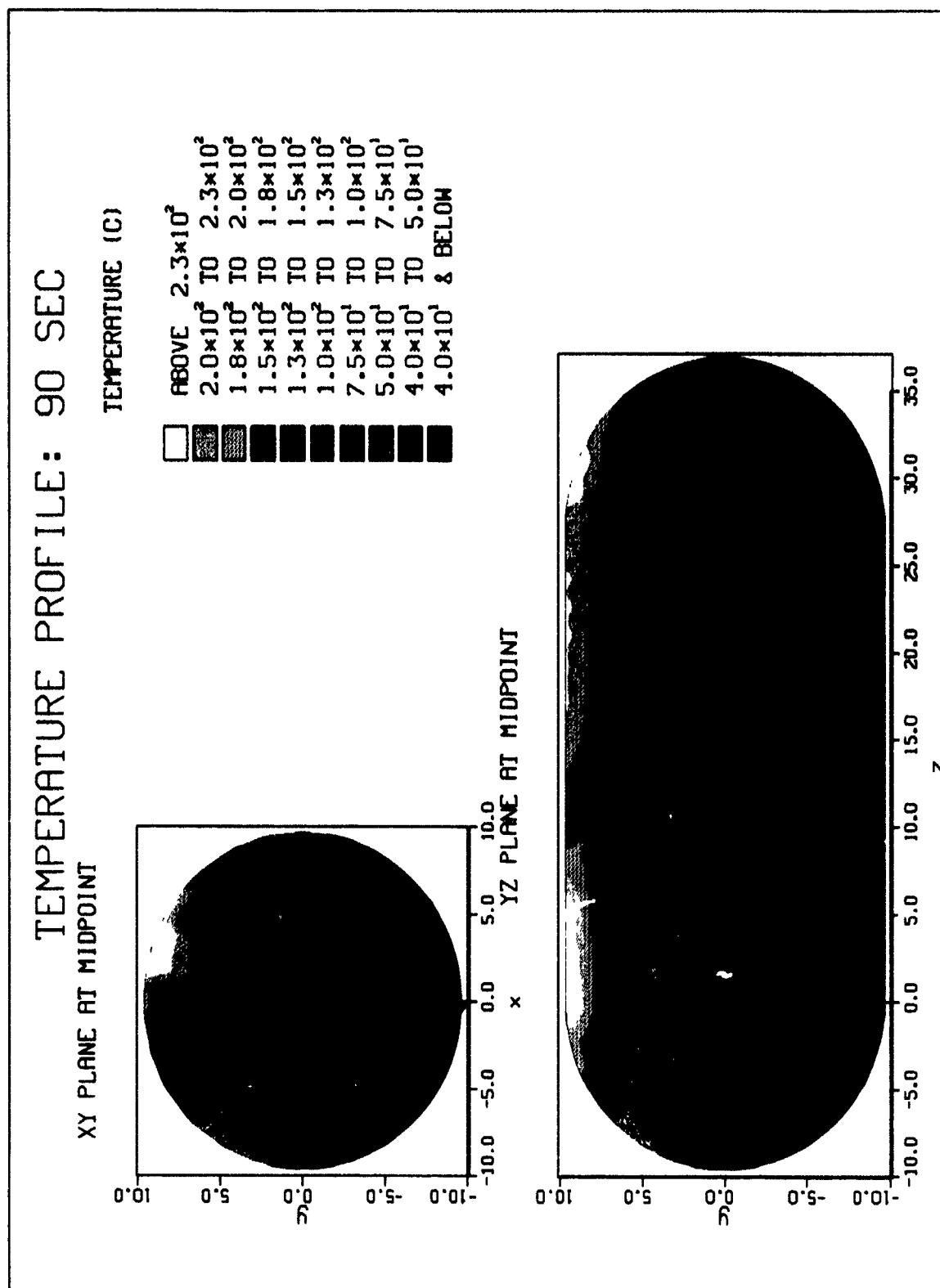


Figure 4.7 Temperature Profiles at 90 Seconds

VELOCITY PROFILE 90 SEC

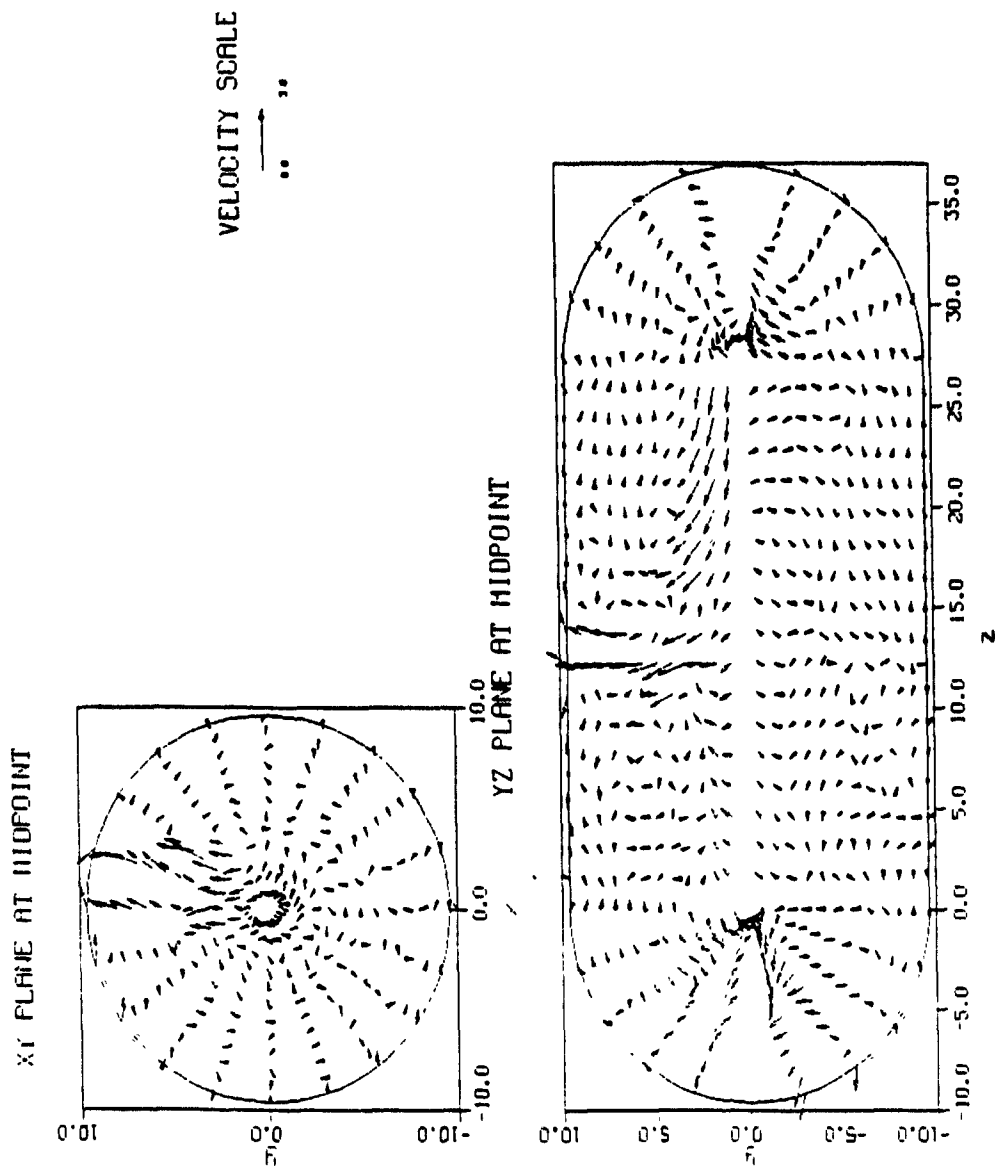


Figure 4.8 Velocity Profile at 90 Seconds

V. CONCLUSIONS AND RECOMMENDATIONS

A. CONCLUSIONS

1. The acquisition of the VAXSTATION 3100 SPX XRJ19 Model 38 workstation with its blend of numerical speed and graphics clarity has greatly enhanced the research.
2. The ventilation equations incorporated into the model in the previous thesis have a great effect on the entire field even when their output velocities are set to zero.
3. Color graphics have provided an excellent means for presenting temperature profile data. Coupled with the Tektronics 4693 color print, CA-DISSPLA™ Graphics Software provides researchers with an excellent tool for displaying scalar data fields.
4. Three dimensional vector fields are difficult to present, ambiguous, and must be reduced to two dimensional images.

B. RECOMMENDATIONS

1. Removal of the ventilation equations is required to regain symmetry observed in previous research. These equations are affecting the entire field although their additive velocities have been set to zero.
2. More sophisticated physical models need to be formulated and incorporated, such as turbulence, gaseous radiation and combustion.
3. Streakline analysis in three dimensions should be conducted to show the path taken of an individual fluid particle as it leaves the flame area. This method may reveal more of the fluid dynamics than current representations of velocity vector fields.
4. The ultimate goal of this project is to develop a model which can predict behavior of fire in shipboard

situations, for example, changing the geometry to fit machinery spaces and berthing compartments. this will offer designers a valuable tool for the construction of safer ships and submarines.

APPENDIX

```

*****
**
**      THREE-DIMENSIONAL NUMERICAL SIMULATION
**      OF A FIRE SPREAD INSIDE A NAVY STORAGE TANK
**
**      DEVELOPED BY :
**      H.Q. YANG AND K.T. YANG
**
**      DEPARTMENT OF AEROSPACE & MECHANICAL ENGINEERING
**      UNIVERSITY OF NOTRE DAME
**      NOTRE DAME, INDIANA, 46556
**
**      DEC. 1986
**
*****
COMMON/R4/XC(93),YC(93),ZC(93),XS(93),YS(93),ZS(93),
      DXXC(93),DYXC(93),DZXC(93),DXXS(93),DYYS(93),DZZS(93)
COMMON/BL1/DX,DY,DZ,VOL,DTIME,VOLDT,THOT,TCOOL,PI,Q,QR
COMMON/BL7/NI,NIP1,NIMI,NJ,NJP1,NJMI,NK,NKP1,NKMI
      ,NIP2,NJP2,NKP2,NA,NAP1,NAMI,NB,NBP1,NBMI,KRUN,NCHIP,NJRA,NWRP
COMMON/BL12/ NWRITE,NTAPE,NTMAX,NTREAL,TIME,SORSUM,ITER
COMMON/BL14/HCOEF,TINF,CNT,ABTURB,BTURB,VISL,VSMAX,QCORRT,PM1,PM2
COMMON/BL16/ CONST1,CONST2,CONST3,CONST4,CONST6,NT,UO,H,UGRT,BUOY,
      CPD,PRT,CONDO,VISO,RHO0,HR,TR,TA,DTEMP,TWRITE,TTAPE,TMAX,GC,RAIR
COMMON/BL20/SIG11(22,16,32),SIG12(22,16,32),SIG22(22,16,32)
      ,SIG13(22,16,32),SIG23(22,16,32),SIG33(22,16,32)
COMMON/BL22/ICHPB(10),NCHPI(10),JCHPB(10),NCHPJ(10),KCHPB(10),
      NCHPK(10),TCHP(10),CPS(10),CONS(10),WFAN(10)
COMMON/BL31/ TOD(22,16,32),ROD(22,16,32),POD(22,16,32)
      ,COD(22,16,32),UOD(22,16,32),VOD(22,16,32),WOD(22,16,32)
COMMON/BL32/ T(22,16,32),R(22,16,32),P(22,16,32)
      ,C(22,16,32),U(22,16,32),V(22,16,32),W(22,16,32)
COMMON/BL33/ TPD(22,16,32),RPD(22,16,32),PPD(22,16,32)
      ,CPD(22,16,32),UPD(22,16,32),VPD(22,16,32),WPD(22,16,32)
COMMON/BL34/ HEIGHT(22,16,32),REQ(22,16,32),
      SMP(22,16,32),SMPP(22,16,32),PP(22,16,32),
      DV(22,16,32),DV(22,16,32),DW(22,16,32)
COMMON/BL36/AP(22,16,32),AE(22,16,32),AW(22,16,32),AX(22,16,32),
      AS(22,16,32),AF(22,16,32),AB(22,16,32),
      SP(22,16,32),SU(22,16,32),RI(22,16,32)
COMMON/BL37/ VLS(22,16,32),COND(22,16,32),NOD(22,16,32),RWALL(579)
      ,CPM(22,16,32),HSZ(3,2),NHSZ(22,16,32),RESORM(93)
COMMON/BL38/NTHCO,CX(12),CY(12),CZ(12),NTH(12,3),TCOUP(12)
COMMON/BL39/ALEW,PCURVE,CONSLRA,PCURMI,PSOUTH,QCORR,PERROR
DIMENSION VFMXC(579,579),T4WALL(579)
DATA X,ITLEFT,SORMAX,XTIME,ITMAX/20,400000,0.40,0.0,4/

```

```

C *** CONST6 : REFERENCE VELOCITY (CM/S)                                00006200
C *** CONSRA : TA**3/(RA*CP*UO*H*H)                                    00006300
C *** NTRWR : NTREAL/NWRITE*NWRITE                                     00006400
C *** NTRWA : NTREAL/NWALT*NWALT                                       00006500
C *** HCONV : HEAT TRANSFER COEFFICIENT ON THE AMBIENT (BTU/H.FT**2K) 00006600
C                                                                           00006700
C                                                                           00006800
C                                                                           00006900
C *** RAD,H: RADIUS OF THE CYLINDRICAL AND SPHERICAL SECTIONS          00007000
C CYL : LENGTH OF THE CYLINDRICAL SECTION OF THE TANK                 00007100
C *** NI : TOTAL NUMBER CELLS IN THETA-DIRECTION                      00007200
C NJ : R-DIRECTION                                                       00007300
C NK : Z AND PHI-DIRECTIONS                                             00007400
C NA : FIRST NUMBER Z-DIRECTION, ALONG THE CYLINDER AXIS              00007500
C NB : LAST NUMBER Z-DIRECTION, ALONG THE CYLINDER AXIS                00007600
C *** HSZ(1,1),HSZ(1,2) FIRST AND LAST COORDIANTE OF HEAT SOURCE      00007700
C                               IN X-DIRECTION (IN DIMENSIONLESS FORM) 00007800
C HSZ(2,1),HSZ(2,2) FIRST AND LAST COORDIANTE OF HEAT SOURCE          00007900
C                               IN Y-DIRECTION (IN DIMENSIONLESS FORM) 00008000
C HSZ(3,1),HSZ(3,2) FIRST AND LAST COORDIANTE OF HEAT SOURCE          00008100
C                               IN Z-DIRECTION (IN DIMENSIONLESS FORM) 00008200
C                                                                           00008300
C *** ICHPB() : STARTING NODAL NUMBER FOR SOLID IN THETA-DIRECTION     00008400
C JCHPB() : R-DIRECTION                                                  00008500
C KCHPB() : Z OR PHI-DIRECTION                                           00008600
C *** NCHPI() : NUMBER OF NODALS FOR SOLID IN THETA-DIRECTION          00008700
C NCHPJ() : R-DIRECTION                                                  00008800
C NCHPK() : Z,PHI-DIRECTION                                              00008900
C ..... 00009000
C open(21,file='input.dat',status='old')
C ..... 00009200
C INPUT DATA 6 00009300
C ..... 00009400
C write(6,*) 'calling input'
C CALL INPUT 00009500
C ..... 00009600
C ..... 00009700
C GENERATE GRID SYSTEM 6 00009800
C ..... 00009900
C write(6,*) 'calling grid'
C CALL GRID 00010000
C ..... 00010100
C ..... 00010200
C *** READ VIEW FACTOR INVERSE MATRIX 6 00010300
C ..... 00010400
C open(11,file='view.dat',status='old')
C do 225 j=1,579
C do 225 i=1,579
C 225 read(11,*) v:mxo(i,i,j)
C CLOSE (11) 00010900
C ..... 00011000
C ..... 00011100
C INITIALIZE THE WHOLE FIELD 6 00011200
C ..... 00011300
C write(6,*) 'calling init'
C CALL INIT 00011400
C ..... 00011500
C ..... 00011600
C START CALCULATION 6 00011700
C ..... 00011800
C ..... 00011900
C NT=0 00012000
C NTIM=0 00012100
C xtime=0.0 00012200
C 300 CONTINUE 00012300
C ..... 00012400
C NT=NT+1 00012500
C ..... 00012600

```

C ***	NTMAX0 HAS THE MEANING AS "NTREAL" WHEN IT IS READ FROM	00012700
C	DISK OR TAPE.	00012800
		00012900
	IF(XTIME .GT. TMAX) GO TO 303	00013000
	NTREAL=NT+NTMAX0	00013100
	TIME=TIME+DTIME	00013200
	XTIME=TIME*H/U0	00013300
	nxtime=jint(xtime)	
	ntwrite=jint(twrite)	
	write(6,*) 'time in seconds=',xtime	00013400
	write(6,*) 'int time=',nxtime	
	write(6,*) 'int time for writing=',ntwrite	
		00013500
C	*****	00013600
C	CALCULATE THE TRANSIENT HEAT INPUT	00013700
C	NOTE IF 1 IN PARENTHESIS, THE BURN RATE IS CALCULATED	00013800
C	BY THE PRESSURE CURVE. IF EQUAL TO TWO, THE BURN RATE	00013900
C	CURVE IS EITHER GIVEN OR ESTIMATED	00014000
C	*****	00014100
	write(6,*) 'calling calq'	
	CALL CALQ(2)	00014200
		00014300
C ***	START CALCULATION	00014400
	ITER=0	00014500
	JTERM=0	00014600
	JTERM=0	00014700
		00014800
		00014900
C	DEFINE THE UPDATED TPD(I,J,K), CPD(I,J,K),RPD(I,J,K)	00015000
C	UPD(I,J,K) AND VPD(I,J,K) FOR THE USE OF CALVIS AND SU(I,J,K)	00015100
		00015200
	DO 48 K=1,NKP1	00015300
	DO 48 J=1,NJP1	00015400
	DO 48 I=1,NIP1	00015500
	TPD(I,J,K)=T(I,J,K)	00015600
	CPD(I,J,K)=C(I,J,K)	00015700
	RPD(I,J,K)=R(I,J,K)	00015800
	UPD(I,J,K)=U(I,J,K)	00015900
	VPD(I,J,K)=V(I,J,K)	00016000
	WPD(I,J,K)=W(I,J,K)	00016100
	48 CONTINUE	00016200
	29 CONTINUE	00016300
	JTERM=JTERM+1	00016400
	301 CONTINUE	00016500
		00016600
		00016700
C	*****	00016800
C	CALCULATE THE RADIATION HEAT FLUX AT EVERY NRAD TIME STEPS	00016900
C	*****	00017000
		00017100
	NRAD = 2	00017200
	IF (MOD(NT,NRAD).NE.0) GOTO 4000	00017300
	CALL RADHT(T4WALL,VFMXC)	00017400
	4000 CONTINUE	00017500
		00017600
		00017700
C	*****	00017800
C	CALCULATE THE TEMPERATURE	00017900
C	*****	
	write(6,*) 'calling calt'	
	CALL CALT	00018000
		00018100
		00018200
C	*****	00018300
C	CALCULATE THE SMOKE CONCENTRATION	00018400
C	*****	
	write(6,*) 'calling calc'	
	CALL CALC	00018500
		00018600
	DO 2000 J=1,NJP1	00018700

DO 2000 I=1,NIP1	00018800
DO 2000 K=1,NKP1	00018900
IF(T(I,J,K).LT.TCOOL) T(I,J,K)=TCOOL	00019000
2000 CONTINUE	00019100
C*****	00019200
C GLOBE PRESSURE CORRECTION FOR ENCLOSED TANK AIR	00019300
C*****	00019400
write(6,*) 'calling globe'	
CALL GLOBE	00019500
	00019600
C*****	00019700
C CALCULATE THE TURBULENT VISCOSITY AND CONDUCTIVITY	00019800
C*****	00019900
write(6,*) 'calling calvis'	
CALL CALVIS	00020000
	00020100
C*****	00020200
C CALCULATE THE DENSITY	00020300
C*****	00020400
DO 100 J=1,NJP1	00020500
DO 100 I=1,NIP1	00020600
DO 100 K=1,NKP1	00020700
IF (MOD(I,J,K).EQ.1) GOTO 100	00020800
AAAA=BUOY*UGRT*HEIGHT(I,J,K)	00020900
R(I,J,K)=(UGRT*P(I,J,K)+(1./EXP(AAAA)))/T(I,J,K)	00021000
100 CONTINUE	00021100
	00021200
C*****	00021300
C CORRECT CONDUCTIVITY OF THE SOLID	00021400
C*****	00021500
IF (NCHIP.EQ.0) GOTO 410	00021600
write(6,*) 'calling solcon'	
CALL SOLCON	00021700
410 CONTINUE	00021800
	00021900
C*****	00022000
C START PRESSURE CORRECTION ITERATIVE LOOP, IT IS THE MAJOR	00022100
C PART OF THE ERROR CONTROL ROUTINE	00022200
C*****	00022300
	00022400
ITER=ITER+1	00022500
	00022600
C*****	00022700
C CALCULATE THE VELOCITY U,V,AND W	00022800
C*****	00022900
write(6,*) 'calling velocities'	
00023000	
CALL CALU	00023100
C CALL STRESS	00023200
C ***	00023300
CALL CALV	00023400
C CALL STRESS	00023500
C ***	00023600
CALL CALW	00023700
write(6,*) 'wfan(1)=',wfan(1)	
C CALL STRESS	00023800
C ***	00023900
	00024000
C*****	00024100
C CALCULATE THE PRESSURE AND STRESS	00024200
C*****	00024300
	00024400
write(6,*) 'calling calp'	
CALL CALP	00024500
CALL STRESS	00024600
	00024700
C*****	00024800
C IF SOURCE TERM IS LARGER THAN 10.0, STOP PROGRAM	00024900

CC

IF (RESORM(ITER).GT.10.0) GOTO 2020

IF(RESORM(ITER) .LE. SORMAX) GO TO 49

IF(ITER .EQ. 1) GO TO 302

ITERM1=ITER-1

IF(RESORM(ITER) .LE. RESORM(ITERM1)) GO TO 302

GO TO 304

302 IF(JTERM .GE. 2) GO TO 37

SOURCE=RESORM(ITER)

GO TO 39

37 IF(RESORM(ITER) .LE. SOURCE) GO TO 38

GO TO 304

38 SOURCE=RESORM(ITER)

39 CONTINUE

C WRITE(6,95) ITER,RESORM(ITER),SORSUM

95 FORMAT(53X,'ITER=',I2,2X,'SOURCE=',F9.6,2X,'SORMUP=',F9.6)

DO 23 K=1,NKP1

DO 23 J=1,NJP1

DO 23 I=1,NIP1

TPD(I,J,K)=T(I,J,K)

CPD(I,J,K)=C(I,J,K)

RPD(I,J,K)=R(I,J,K)

UPD(I,J,K)=U(I,J,K)

VPD(I,J,K)=V(I,J,K)

WPD(I,J,K)=W(I,J,K)

PPD(I,J,K)=P(I,J,K)

23 CONTINUE

JJTERM=0

IF(ITER .EQ. ITMAX) GO TO 49

IF(JJTERM .EQ. 2) GO TO 35

IF(ITER .EQ. 4) GO TO 29

35 CONTINUE

IF(JJTERM .EQ. 3) GO TO 58

IF(ITER .EQ. 7) GO TO 29

58 CONTINUE

JJTERM=0

GO TO 301

304 CONTINUE

JJTERM=JJTERM+1

C IF(JJTERM .EQ. 1) WRITE(6,95) ITER,RESORM(ITER),SORSUM

IF(JJTERM .EQ. 1) GO TO 41

IF(JJTERM .EQ. 2 .AND. JJTERM .EQ. 1 .AND. ITER .NE. 5) GO TO 41

GO TO 82

41 CONTINUE

DO 40 K=1,NKP1

DO 40 J=1,NJP1

DO 40 I=1,NIP1

R(I,J,K)=RPD(I,J,K)

U(I,J,K)=UPD(I,J,K)

V(I,J,K)=VPD(I,J,K)

W(I,J,K)=WPD(I,J,K)

P(I,J,K)=PPD(I,J,K)

40 CONTINUE

IF(ITER .EQ. ITMAX) GO TO 49

GO TO 29

82 CONTINUE

DO 43 K=1,NKP1

DO 43 J=1,NJP1

DO 43 I=1,NIP1

T(I,J,K)=TPD(I,J,K)

C(I,J,K)=CPD(I,J,K)

R(I,J,K)=RPD(I,J,K)

U(I,J,K)=UPD(I,J,K)

V(I,J,K)=VPD(I,J,K)

W(I,J,K)=WPD(I,J,K)

P(I,J,K)=PPD(I,J,K)

00025000

00025100

00025200

00025300

00025400

00025500

00025600

00025700

00025800

00025900

00026000

00026100

00026200

00026300

00026400

00026500

00026600

00026700

00026800

00026900

00027000

00027100

00027200

00027300

00027400

00027500

00027600

00027700

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00028000

00028100

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00028900

00029000

00029100

00029200

00029300

00029400

00029500

00029600

00029700

00029800

00029900

00030000

00030100

00030200

00030300

00030400

00030500

00030600

00030700

00030800

00030900

00031000

00031100

00031200

00031300

00031400

00031500

00031600

00031700

```

43 CONTINUE                                00031800
IF(ITER.EQ. ITMAX) GO TO 49                00031900
IF((JTERM.EQ. 3 .AND. ITER.NE. 8) .OR. JJTERM.EQ. 2) GO TO 49 00032000
GO TO 301                                  00032100
49 CONTINUE                                00032200
                                           00032300
                                           00032400
ITERT=ITERT+ITER                          00032500
C#####                                00032600
C GO TO THE PRESSURE TRACKING SUBROUTINE ,PRINT OUT #          00032700
C RESULTS IF AT THE RIGHT TIME INTERVAL #                      00032800
C#####                                00032900
write(6,*) 'calling ptrack'
                                           00033000
CALL PTRACK                                00033100
IF (MOD(ntreal,NWRP).EQ.0) CALL OUT(1)    00033200
                                           00033300
C#####                                00033400
C FIND TEMPERATURES AT THERMOCOUPLE POINTS AND PRINT OUT #    00033500
C IF AT THE RIGHT TIME INTERVAL #                              00033600
C#####                                00033700
if (ntheo.eq.0) goto 2422
CALL TCP                                  00033800
IF (MOD(NTREAL,NWRP).EQ.0) CALL OUT(2)    00033900
2422 CONTINUE                             00034000
IF (MOD(nxttime,ntwrit).EQ.0) CALL OUT(3)
00034100
C IF(NTREAL.EQ. NTREAL/NWRITE*NWRITE) CALL OUT(3)              00034200
505 CONTINUE                             00034300
IF((XTIME+DIME*H/UO).GE. TMAX) GO TO 277 00034400
                                           00034500
C *** .....                                00034600
C CALL TLEFT(IT)                                                00034700
C 123 FORMAT(' TLEFT = ',I10)                                  00034800
C ITO=IT                                                         00034900
C IF(IT.IT.TLEFT) CALL OUT(3)                                    00035000
C *** .....                                00035100
                                           00035200
                                           00035300
C *** RESET THE OLD TIME VALUES TOD, ROD, UOD, VOD AND POD. 00035400
                                           00035500
DO 305 K=1,NKP1                                                  00035600
DO 305 J=1,NJP1                                                  00035700
DO 305 I=1,NIP1                                                  00035800
TOD(I,J,K)=T(I,J,K)                                             00035900
COD(I,J,K)=C(I,J,K)                                             00036000
ROD(I,J,K)=R(I,J,K)                                             00036100
UOD(I,J,K)=U(I,J,K)                                             00036200
VOD(I,J,K)=V(I,J,K)                                             00036300
WOD(I,J,K)=W(I,J,K)                                             00036400
POD(I,J,K)=P(I,J,K)                                             00036500
305 CONTINUE                                                     00036600
                                           00036700
C #####                                00036800
C THIS WRITING IS FOR PLOTTINGS                                00036900
C #####                                00037000
C IF(NTREAL.NE. NTREAL/NTAPE*NTAPE)GOTO 522                    00037100
C IWRITE=10                                                       00037200
C WRITE(9,*)                                                       00037300
C & TIME,NTREAL,T,R,U,V,W,P,CPM,COND,VIS,ORNET,ITERT,QCORRT,PM1,PM2, 00037400
C & H,TA,UC,CONDO,VISO,RHOO,NI,NJ,NK,NIP1,NJP1,NKP1,NIM1,NJM1,NKM1, 00037500
C & XC,YC,ZC,XS,YS,ZS,DXXC,DYYC,DZZC,DXXS,DYYS,DZZS            00037600
C WRITE(6,*) 'THE TIME WHEN THE DATA WAS STORED ON DISK IS:' 00037700
C & XTIME                                                         00037800
C #####                                00037900
                                           00038000
                                           00038100
                                           00038200
522 CONTINUE                                                     00038300

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C ***	00038400
C CALL TLEFT(IT)	00038500
C IF(IT.IT.TLEFT) GO TO 166	00038600
C ***	00038700
C TIMREM IS USED TO CALCULATE THE CPU TIME REMAINING AT NPS	00038800
	00038900
	00039000
C IF (TIMREM(0.).LE.80.) GOTO 166	00039100
do 222 k=1,nkpl	
do 222 i=1,nipl	
do 222 j=1,njpl	
WRITE(9,555) t(i,j,k),u(i,j,k),v(i,j,k),w(i,j,k)	
write(9,555) p(i,j,k),cpm(i,j,k),cond(i,j,k),vis(i,j,k)	
222 continue	
write(9,556) time,qr,qcorrt,pm1,pm2,xxxxx	
write(9,556) h,ta,u0,cond0,vis0,rho0	
write(9,557) ntreal,ni,nj,nk,nipl,njpl,nkpl,niml,njml,nkml,icert	
write(9,556) xc,yc,zc,xa,ya,za	
write(9,556) dxxc,dyyc,dzxc,dxxs,dyyS,dzss	
555 format(4(3x,e12.4))	
556 format(6(1x,e10.3))	
557 format(11i4)	
REWIND 9	00039200
GO TO 300	00039300
303 CONTINUE	00039400
277 CONTINUE	00039500
	00039600
WRITE(6,1111)	00039700
1111 FORMAT(2X,'***** THE MAXIMUM TIME HAS BEEN REACHED *****',I8)	00039800
C GO TO 172	00039900
	00040000
C ***	00040100
C 166 IF(NTREAL.NE. NTREAL/NTAPE*NTAPE) then	
c234567	
do 223 k=1,nkpl	
do 223 i=1,nipl	
do 223 j=1,njpl	
WRITE(9,555) t(i,j,k),u(i,j,k),v(i,j,k),w(i,j,k)	
write(9,555) p(i,j,k),cpm(i,j,k),cond(i,j,k),vis(i,j,k)	
223 continue	
write(9,556) time,qr,qcorrt,pm1,pm2,xxxxx	
write(9,556) h,ta,u0,cond0,vis0,rho0	
write(9,557) ntreal,ni,nj,nk,nipl,njpl,nkpl,niml,njml,nkml,icert	
write(9,556) xc,yc,zc,xa,ya,za	
write(9,556) dxxc,dyyc,dzxc,dxxs,dyyS,dzss	
REWIND 9	
C ***	00040700
	00040800
GOTO 172	00040900
2020 CONTINUE	00041000
WRITE (6,') ' RESIDUAL MASS IS LARGER THAN 10.0, PROGRAM STOPS'	00041100
172 CONTINUE	00041200
STOP	00041300
END	00041400
	00041500
	00041600
	00041700
C	00041800
.....	00041900
SUBROUTINE INPUT	00042000
.....	00042100
THIS SUBROUTINE SETS UP REQUIRED VALUES TO BEGIN THE PROGRAM.	00042200
VARIABLES ARE:	00042300
KRUN = WHEN EQUAL TO ONE, READ FROM THE	00042400
RESTART DISK, ELSE FROM THE JOL	00042500
NCHIP = NUMBER OF SOLID PIECES	00042600
NWRP = NUMBER OF TIME STEPS TO WRITE ON THE	00042700
PAPER	

"	NTHCO	=	NUMBER OF THERMOCOUPLES TO PRINT OUT	*00042800
"	TMAX	=	MAXIMUM TIME ALLOWED (REAL)	*00042900
"	TWRITE	=	SECONDS IN REAL TIME TO PRINT THE	*00043000
"			P,V,T FIELDS ON PAPER	*00043100
"	TTAPE	=	TIME INTERVAL TO WRITE ON THE TAPE	*00043200
"	DTIME	=	TIME STEP (DIMENSIONLESS)	*00043300
"	HSZ	=	HEAT SOURCE SIZE, USED TO CALCULATE	*00043400
"			THE VOLUME OF THE FIRE CELL	*00043500
"	ICHPB	=	FIRST SOLID NODE IN THETA DIRECTION	*00043600
"	JCHPB	=	FIRST SOLID NODE IN R DIRECTION	*00043700
"	KCHPB	=	FIRST SOLID NODE IN PHI DIRECTION	*00043800
"	NCHPI	=	NUMBER OF NODES IN THETA DIRECTION	*00043900
"	NCHPJ	=	NUMBER OF NODES IN R DIRECTION	*00044000
"	NCHPK	=	NUMBER OF NODES IN PHI DIRECTION	*00044100
"	CX,CY,CZ	=	THERMOCOUPLE POSITIONS IN THETA,R,PHI	*00044200
"				*00044300
"				*00044400
"				*00044500
"				*00044600
"				*00044700
"				*00044800
"				*00044900
"				*00045000
"				*00045100
"				*00045200
"				*00045300
"				*00045400
"				*00045500
"				*00045600
"				*00045700
"				*00045800
"				*00045900
"				*00046000
"				*00046100
"				*00046200
"				*00046300
"				*00046400
"				*00046500
"				*00046600
"				*00046700
"				*00046800
"				*00046900
"				*00047000
"				*00047100
"				*00047200
"				*00047300
"				*00047400
"				*00047500
"				*00047600
"				*00047700
"				*00047800
"				*00047900
"				*00048000
"				*00048100
"				*00048200
"				*00048300
"				*00048400
"				*00048500
"				*00048600
"				*00048700
"				*00048800
"				*00048900
"				*00049000
"				*00049100
"				*00049200
"				*00049300
"				*00049400
"				*00049500

COMMON/R4/XC(93),YC(93),ZC(93),XS(93),YS(93),ZS(93),
 & DXXC(93),DYXC(93),DZXC(93),DXXS(93),DYXS(93),DZXS(93)
 COMMON/BL1/DX,DY,DZ,VOL,DTIME,VOLDT,THOT,TCOOL,PI,Q,QR
 COMMON/BL7/N1,NIP1,NIM1,NJ,NJP1,NJM1,NK,NKP1,NKM1
 & ,NIP2,NJP2,NKP2,NA,NAP1,NAM1,NB,NBP1,NBM1,KRUN,NCHIP,NJRA,NWRP
 COMMON/BL12/NWRITE,NTAPE,NTMAXO,NTREAL,TIME,SORSUM,ITER
 COMMON/BL14/HCOEF,TINF,CNT,ASTURB,STURB,VISL,VISMAX,QCORRT,PM1,PM200045100
 COMMON/BL16/CONST1,CONST2,CONST3,CONST4,CONST6,NT,UO,H,UGRT,BUOY,00045200
 & CPO,PRT,CONDO,VISO,RHOO,HR,TR,TA,DTEMP,TWRITE,TTAPE,TMAX,GC,RAIR00045300
 COMMON/BL20/SIG11(22,16,32),SIG12(22,16,32),SIG22(22,16,32)
 & ,SIG13(22,16,32),SIG23(22,16,32),SIG33(22,16,32)
 COMMON/BL22/ICHPB(10),NCHPI(10),JCHPB(10),NCHPJ(10),KCHPB(10),
 & NCHPK(10),TCHP(10),CPS(10),CONS(10),WFAN(10)
 COMMON/BL31/TOD(22,16,32),ROD(22,16,32),POD(22,16,32)
 & ,COD(22,16,32),UOD(22,16,32),VOD(22,16,32),WOD(22,16,32)
 COMMON/BL32/T(22,16,32),R(22,16,32),P(22,16,32)
 & ,C(22,16,32),U(22,16,32),V(22,16,32),W(22,16,32)
 COMMON/BL33/TPD(22,16,32),RPD(22,16,32),PPD(22,16,32)
 & ,CPD(22,16,32),UPD(22,16,32),VPD(22,16,32),WPD(22,16,32)
 COMMON/BL34/HEIGHT(22,16,32),REQ(22,16,32),
 & SMP(22,16,32),SMPP(22,16,32),PP(22,16,32),
 & DU(22,16,32),DV(22,16,32),DW(22,16,32)
 COMMON/BL36/AP(22,16,32),AE(22,16,32),AW(22,16,32),AN(22,16,32),
 & AS(22,16,32),AF(22,16,32),AB(22,16,32),
 & SP(22,16,32),SU(22,16,32),RI(22,16,32)
 COMMON/BL37/VIS(22,16,32),COND(22,16,32),NOD(22,16,32),RWALL(579)00047000
 & ,CPM(22,16,32),HSZ(3,2),NHSZ(22,16,32),RESORM(93)
 COMMON/BL38/NTHCO,CX(12),CY(12),CZ(12),NTH(12,3),TCOUP(12)
 00047100
 00047200
 00047300
 00047400
 00047500
 00047600
 00047700
 00047800
 00047900
 00048000
 00048100
 00048200
 00048300
 00048400
 00048500
 00048600
 00048700
 00048800
 00048900
 00049000
 00049100
 00049200
 00049300
 00049400
 00049500

C #1. READ IN DATA TO INDICATE EITHER KRUN=0 OR 1
 READ(21,*) KRUN,NCHIP,NWRP,NTHCO
 00047500
 00047600
 00047700

C #2. READ IN DATA SET 1 - 6 DATA
 READ(21,*) TMAX,TWRITE,TTAPE,DTIME
 00047800
 00047900
 00048000

C #3. READ IN DATA FOR HEAT SOURCE
 READ(21,*) HSZ(1,1),HSZ(1,2),HSZ(2,1),HSZ(2,2),HSZ(3,1),HSZ(3,2)
 WRITE(6,20) HSZ(1,1),HSZ(1,2),HSZ(2,1),HSZ(2,2),HSZ(3,1),HSZ(3,2)
 20 FORMAT (/,'20X','HEAT SOURCE LOCATION IS IN THE VOLUME (NON-DIME',
 & 'NSIONAL WITH RESPECT TO RADIUS)',
 & /,'5X','FROM ',F8.4,' TO ',F8.4,' IN X-DIRECTION',
 & /,'5X','FROM ',F8.4,' TO ',F8.4,' IN Y-DIRECTION',
 & /,'5X','FROM ',F8.4,' TO ',F8.4,' IN Z-DIRECTION',/)
 00048100
 00048200
 00048300
 00048400
 00048500
 00048600
 00048700
 00048800
 00048900
 00049000
 00049100
 00049200
 00049300
 00049400
 00049500

C #4. READ IN DECK DATA
 IF (NCHIP.EQ.0) GOTO 16
 PRINT *
 00049200
 00049300
 00049400
 00049500

```

PRINT *, ' THE REGION BOUNDED BY SOLID'
DO 19 N=1,NCHIP
READ (21,*) ICHPB(N),NCHPI(N),JCHPB(N),NCHPJ(N),KCHPB(N),
NCHPK(N),TCHP(N),CPS(N),CONS(N),WFAN(N)
WRITE (6,10) N, ICHPB(N),NCHPI(N),JCHPB(N),NCHPJ(N),KCHPB(N),
NCHPK(N),TCHP(N),CPS(N),WFAN(N),CONS(N)
10 FORMAT (2X,'N= ',I2,' ICHPB= ',I2,' NCHPI= ',I2,' JCHPB= ',I2,
' NCHPJ= ',I2,' KCHPB= ',I2,' NCHPK= ',I2,' TCHP= ',F8.5,
' CPS= ',F8.5,' WFAN = ',F12.5,' CONS= ',F12.5,/)
19 CONTINUE
16 CONTINUE
write(6,*) 'nchip=',nchip

if(nthco.eq.0) goto 119
C #5. INPUT THERMOCOUPLE COORDINATE
C IN TERMS OF X(THETA), Y(RADIUS), Z(PHI)

PRINT *
PRINT *, ' THERMOCOUPLE POSITION IN TERMS OF THETA, R, PHI'
PRINT *
DO 110 I=1,NTHCO
READ (21,*) CX(I),CY(I),CZ(I)
WRITE (6,*) I, CX(I),CY(I),CZ(I)
110 CONTINUE
119 continue
RETURN
END

C *****
C SUBROUTINE INIT
C *****
* THIS SUBROUTINE INITIALIZES THE FIELD AND CONSTANTS WITH RESPECT
* TO INITIAL START OR RESTARTING CAPABILITY.
* VARIABLES ARE :
* TIME = DIMENSIONLESS TIME
* UO = CHARACTERISTIC VELOCITY (1 FT/SEC)
* H = CHARACTERISTIC LENGTH (RADIUS(9.6FT))
* TR = TEMP IN DEGREES KELVIN
* TA = TEMP IN DEGREES RANKINE
* VISO = REFERENCE VISCOSITY (NNDIM)
* VISL = MINIMUM VISCOSITY (NNDIM)
* VISMAX = MAXIMUM VISCOSITY (NNDIM)
* RR = RADIUS IN CM
* CLNDO = REFERENCE CONDUCTIVITY
* CO = INITIAL SMOKE CONCENTRATION
* NJRA = POINT OF RADIATION IN J DIRECTION
* LOCATED ON THE INNER SOLID BOUNDARY
* HCONV = HEAT TRANSFER COEFFICIENT
* HCOEF = DIMENSIONLESS HEAT TRANSFER COEF
* CONST1 = USED TO NONDIMENSIONALIZE PRESSURE
* RHOO = REFERENCE DENSITY
* GC = GRAVITY CONSTANT
* BUOY = BUOYANCY FORCE CONSTANT
* UGRT = PERFECT GAS LAW NONDIMENSIONAL CONSTANT
* CPO = REFERENCE SPECIFIC HEAT
* NWRITE/ = NONDIMENSIONAL FORMS OF TWRITE AND
* NTAPE = TTAPE
* MATRICES OF THE FORM
* _OD = DIMENSIONLESS PARAMETER AT OLD TIME
* _ = DIMENSIONLESS PARAMETER
* _PD = UPDATED DIMENSIONLESS PARAMETER
* WHERE THE PARAMETERS ARE
* U,V,W = VELOCITY IN THETA, R , PHI DIRECTION
* T,P,C = TEMP, PRESSURE, AND SMOKE CONCENTRATION

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*      DU,DV,DZ  =      USED IN PRESSURE CORRECTION SUBROUTINE *00056300
*      PP        =      CORRECTED PRESSURE (P') *00056400
*      SU        =      SOURCE TERM *00056500
*      SP        =      TERM AT P NODAL POINT FOR BOUNDARY *00056600
*                  CONDITIONS *00056700
*      AP        =      COEFFICIENT AT NODAL POINT *00056800
*      AE,AW,AN  =      COEFFICIENTS AT PTS EAST, WEST, NORTH, *00056900
*      AS,AF,AB  =      SOUTH, FRONT, AND BACK *00057000
*      SMP        =      RESIDUAL MASS SUMMATION OF NODAL POINT *00057100
*      SMPP       =      LENGTH SCALE FOR TURBULENCE *00057200
*      CPM        =      MEAN SPECIFIC HEAT *00057300
*      VIS        =      VISCOSITY *00057400
*      COND       =      CONDUCTIVITY MATRIX *00057500
*      NHSZ       =      WHEN THIS VALUE EQUALS ZERO, THERE IS *00057600
*                  NO HEAT SOURCE LOCATED AT THE NODE *00057700
*      NOD        =      IF EQUAL TO ZERO, LIQUID *00057800
*                  IF EQUAL TO ONE, SOLID *00057900
*      _B,_E      =      BEGINNING AND ENDING NODAL POINT FOR *00058000
*                  THE SOLID IN I,J,K *00058100
*      REQ        =      DENSITY AT EQUILIBRIUM *00058200
*      NIP1       =      NODAL POINT IN I PLUS 1 (OTHERS SIMILAR) *00058300
*      XC,YC,ZC   =      THETA,R,PHI LOCATION OF NODAL POINT OF *00058400
*                  A CENTER CELL *00058500
*      DXXC,DYYC  =      LENGTH AROUND THE CENTER CELL *00058600
*      DZ2C       =      *00058700
*      XS,YS,ZS   =      THETA,R,PHI LOCATION OF NODAL POINT OF *00058800
*                  A STAGGERED CELL *00058900
*      DXXS,DYYS  =      LENGTH AROUND THE STAGGERED CELL *00059000
*      DZ2S       =      *00059100
*      CX,CY,CZ   =      LOCATION OF THERMOCOUPLE IN THETA,R,PHI *00059200
*.....*00059300
COMMON/R4/XC(93),YC(93),ZC(93),XS(93),YS(93),ZS(93),
*      DXXC(93),DYYC(93),DZ2C(93),DXXS(93),DYYS(93),DZ2S(93) *00059400
COMMON/BL1/DX,DY,DZ,VOL,DTIME,VOLDT,THOT,TCOOL,PI,Q,QR *00059500
COMMON/BL7/N1,NIP1,NIM1,NJ,NJP1,NJM1,NK,NKP1,NKM1 *00059600
*      ,NIP2,NJP2,NKP2,NA,NAP1,NAM1,NB,NBP1,NBM1,KNUN,NCHIP,NJRA,NWRP *00059700
COMMON/BL12/NWRITE,NTAPE,NTMAXO,NTREAL,TIME,SORSUM,ITER *00059800
COMMON/BL14/HCOEF,TINF,CNT,ABTURB,BTURB,VISL,VISMAX,QCORRT,PM1,PM2 *00059900
COMMON/BL16/CONST1,CONST2,CONST3,CONST4,CONST6,NT,UC,H,UGRT,BUOY *00060000
*      CPD,PRC,CONDO,VISO,RHOO,HR,TR,TA,DTEMP,TWRITE,TTAPE,TMAX,GC,RAIRO *00060100
COMMON/BL20/SIG11(22,16,32),SIG12(22,16,32),SIG22(22,16,32) *00060200
*      ,SIG13(22,16,32),SIG23(22,16,32),SIG33(22,16,32) *00060300
COMMON/BL22/ICHPB(10),NCHPI(10),JCHPB(10),NCHPJ(10),KCHPB(10),
*      NCHPK(10),TCHP(10),CPS(10),CONS(10),WFAN(10) *00060400
COMMON/BL31/TOD(22,16,32),ROD(22,16,32),POD(22,16,32) *00060500
*      ,UOD(22,16,32),VOD(22,16,32),WOD(22,16,32) *00060600
COMMON/BL32/T(22,16,32),R(22,16,32),P(22,16,32) *00060700
*      ,C(22,16,32),U(22,16,32),V(22,16,32),W(22,16,32) *00060800
COMMON/BL33/TPD(22,16,32),RPD(22,16,32),PPD(22,16,32) *00060900
*      ,CPD(22,16,32),UPD(22,16,32),VPD(22,16,32),WPD(22,16,32) *00061000
COMMON/BL34/HRIGHT(22,16,32),REQ(22,16,32),
*      SMP(22,16,32),SMPP(22,16,32),PP(22,16,32),
*      DU(22,16,32),DV(22,16,32),DW(22,16,32) *00061100
COMMON/BL36/AP(22,16,32),AE(22,16,32),AW(22,16,32),AN(22,16,32),
*      AS(22,16,32),AF(22,16,32),AB(22,16,32),
*      SP(22,16,32),SC(22,16,32),RI(22,16,32) *00061200
COMMON/BL37/VIS(22,16,32),COND(22,16,32),NOD(22,16,32),RWALL(579) *00061300
*      ,CPM(22,16,32),HSZ(3,2),NHSZ(22,16,32),RESORM(93) *00061400
COMMON/BL38/NTHCO,CX(12),CY(12),CZ(12),NTH(12,3),TCOUP(12) *00061500
COMMON/BL39/ALEW,PCURVE,CONSRA,PCURM1,PSOUTH,QCORR,PERROR *00061600
DATA GRAV/32.1// *00061700
*00061800
C ***      INTRODUCE GIVEN PARAMETERS *00061900
*00062000
TIME=0. *00062100
TR=TA/1.9 *00062200
H=9.6 *00062300
VISO=VISO/UC/H *00062400
*00062500
*00062600
*00062700
*00062800
*00062900
*00063000

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```

VLSL=VISO
VLSMAX=400.*VLSL
HR=H*30.48
CONDC=VISO/PRT
PI=4.*ATAN(1.)
ALEW = 1.0
NJRA=15
00063100
00063200
00063300
00063400
00063500
00063600
00063700
00063800
00063900
00064000
00064100
00064200
00064300
00064400
00064500
00064600
00064700
00064800
00064900
00065000
00065100
00065200
00065300
00065400
00065500
00065600
00065700
00065800
00065900
00066000
00066100
00066200
00066300

C THE HEAT TRANSFER COEFFICIENT IS IN BTU/HR/FT**2/F
HCONV=15.0
HCOEF=HCONV/(3600.*CPO*RHOO*UO)
CO = 0.0

CONST1=RHOO*UO*UO/(GC*14.696*144.)
CONST3=1.8/TA
CONST4=H*30.48
CONST6=UO*30.48
NTMAXO=0

BUOY=GRAV*H/(UO*UO)
UGRT=UO*UO/(GC*RAIR*TA)
TCOOL=1.0
CONSLA=TA*TA*TA/(RHOO*CPO*UO*3600.)*1.714E-9

WRITE(6,200) TR,CONDO,VISO,CPO,HR,DTIME,HCONV
200 FORMAT(5X, 'THE REFERENCE TEMPERATURE AND THERMAL PROPERTIES',/,
6 /,3X, 'T' = ',F10.4,'K, CONDO = ',E12.6,
6 /,3X, 'VISO = ',E12.6,' CPO = ',E12.6,
6 /,3X, 'RADIUS = ',E12.6,' CM',
6 /,3X, 'DTIME = ',E12.6,
6 /,3X, 'HCONV = ',E12.6,/)

NWRITE=jint(TWRITE*UO/DTIME/H)
00066400
NTAPE=jint(TTAPE*UO/DTIME/H)
00066500
C *** PRINT OUT INPUT INFORMATION
00066600
00066700
00066800
00066900
00067000
00067100
00067200
00067300
00067400
00067500
00067600
00067700
00067800
00067900
00068000
00068100
00068200
00068300
00068400
00068500
00068600
00068700
00068800
00068900
00069000
00069100
00069200
00069300
00069400
00069500
00069600

C *** INITIALIZE VARIABLE FIELD
DO 220 J=1,NJPI
DO 220 I=1,NIP1
DO 220 K=1,NKPI
ROD(I,J,K)=1.
R(I,J,K)=1.
RPD(I,J,K)=1.
UOD(I,J,K)=0.
U(I,J,K)=0.
UPD(I,J,K)=0.
VOD(I,J,K)=0.
V(I,J,K)=0.
VPD(I,J,K)=0.
W(I,J,K)=0.
WPD(I,J,K)=0.
WOD(I,J,K)=0.
POD(I,J,K)=0.
P(I,J,K)=0.
PPD(I,J,K)=0.
OU(I,J,K)=0.
OV(I,J,K)=0.
OW(I,J,K)=0.

```


SU(I,J,K)=0.	00069700
SP(I,J,K)=0.	00069800
PP(I,J,K)=0.	00069900
AP(I,J,K)=0.	00070000
AW(I,J,K)=0.	00070100
AE(I,J,K)=0.	00070200
AN(I,J,K)=0.	00070300
AS(I,J,K)=0.	00070400
AF(I,J,K)=0.	00070500
AB(I,J,K)=0.	00070600
SMP(I,J,K)=0.	00070700
SMPP(I,J,K)=0.	00070800
VIS(I,J,K)=VISL	00070900
COND(I,J,K)=CONDO	00071000
CPM(I,J,K)=1.0E0	00071100
TOD(I,J,K)=1.0E0	00071200
T(I,J,K)=TOD(I,J,K)	00071300
TPD(I,J,K)=TOD(I,J,K)	00071400
COD(I,J,K)=CO	00071500
C(I,J,K)=COD(I,J,K)	00071600
CPD(I,J,K)=COD(I,J,K)	00071700
NHSZ(I,J,K)=0	00071800
NOD(I,J,K)=0	00071900
220 CONTINUE	00072000
	00072100
	00072200
C *** DETERMINE THE POSITION OF HEAT SOURCE	00072300
DO 300 I=2,NI	00072400
DO 300 J=2,NJ	00072500
	00072600
	00072700
C CHANGE TO RECTANGULAR COORDINATES	00072800
XX=YC(J)*COS(XC(I))	00072900
YY=YC(J)*SIN(XC(I))	00073000
	00073100
C CHECK TO SEE IF IN HS CONTROL VOLUME, IF SO SET NHSZ=1	00073200
IF (XX.LT.NHSZ(1,1).OR.XX.GT.NHSZ(1,2)) GOTO 310	00073300
IF (YY.LT.NHSZ(2,1).OR.YY.GT.NHSZ(2,2)) GOTO 310	00073400
NHSZ(I,J,16)=1	00073500
NHSZ(I,J,17)=1	00073600
315 FORMAT (2X,10(4X,I4,2X,I4))	00073700
GOTO 300	00073800
310 CONTINUE	00073900
300 CONTINUE	00074000
	00074100
	00074200
C *** DEFINE THERMAL PROPERTIES OF DECK AND SOLID	00074300
IF (NCHIP.EQ.0) GOTO 410	00074400
DO 402 N=1,NCHIP	00074500
IB=ICHPB(N)	00074600
IE=IB+NCHPI(N)-1	00074700
JB=JCHPB(N)	00074800
JE=JB+NCHPJ(N)-1	00074900
KB=KCHPB(N)	00075000
KE=KB+NCHPK(N)-1	00075100
DO 405 I=IB,IE-1	00075200
DO 405 J=JB,JE-1	00075300
DO 405 K=KB,KE-1	00075400
COND(I,J,K)=CONDO*CONS(N)	00075500
CPM(I,J,K)=CPO*CPS(N)	00075600
NOD(I,J,K)=1	00075700
405 CONTINUE	00075800
402 CONTINUE	00075900
410 CONTINUE	00076000
	00076100
	00076200
	00076300
	00076400

C *** FOR CONTINUING RUN, READ DATA FROM TAPE OR DISK	00076500
IF(KRUN.EQ. 1) GO TO 9997	00076600
GO TO 15	00076700
9997 DO 222 K=1,NKPL	00076800
DO 222 I=1,NIP1	00076900
DO 222 J=1,NJPL	
READ(9,555) T(I,J,K),U(I,J,K),V(I,J,K),W(I,J,K)	
READ(9,555) P(I,J,K),CPM(I,J,K),COND(I,J,K),VIS(I,J,K)	
222 CONTINUE	
READ(9,556) TIME,QR,QCORRT,PM1,PM2,XXXXX	
READ(9,556) XXN,XXTA,XXU0,XXCOND0,XXVIS0,XXRHO0	
READ(9,557) NCREAL,N1,NJ,NK,NIP1,NJPL,NKPL,NIM1,NJML,NKML,ITER	
READ(9,556) XC,YC,ZC,XS,YS,ZS	
READ(9,556) DXXC,DYYC,DZZC,DXXS,DYYS,DZZS	
555 FORMAT(4(3X,E12.4))	
556 FORMAT(6(1X,E10.3))	
557 FORMAT(11I4)	
REWIND 9	
WRITE(6,*)NTMAX0	00077800
15 CONTINUE	00077900
	00078000
	00078100
C *** DEFINE HEIGHT OF NODE POINTS AND COMPUTE HYDROSTATIC	00078200
EQUILIBRIUM DENSITY REQ(I,J,K)	00078300
	00078400
	00078500
DO 13 K=1,NKPL	00078600
DO 13 I=1,NIP1	00078700
DO 13 J=1,NJPL	00078800
DHY=YC(J)*SIN(XC(I))*SIN(ZC(K))	00078900
HEIGHT(I,J,K)=DHY	00079000
13 CONTINUE	00079100
C	00079200
DO 229 J=1,NJPL	00079300
DO 229 I=1,NIP1	00079400
DO 229 K=1,NKPL	00079500
AAAA=-BUOY*UGRT*HEIGHT(I,J,K)	00079600
REQ(I,J,K)=EXP(AAAA)	00079700
IF(KRUN.NE. 0) GO TO 229	00079800
RPD(I,J,K)=REQ(I,J,K)/TPD(I,J,K)	00079900
ROD(I,J,K)=RPD(I,J,K)	00080000
R(I,J,K)=RPD(I,J,K)	00080100
229 CONTINUE	00080200
	00080300
C *** INITIALIZE U,V,T,R,P FIELD	00080400
	00080500
DO 210 K=1,NKPL	00080600
DO 210 J=1,NJPL	00080700
DO 210 I=1,NIP1	00080800
T(I,J,K)=TOD(I,J,K)	00080900
C(I,J,K)=COD(I,J,K)	00081000
R(I,J,K)=ROD(I,J,K)	00081100
U(I,J,K)=UOD(I,J,K)	00081200
V(I,J,K)=VOD(I,J,K)	00081300
W(I,J,K)=WOD(I,J,K)	00081400
P(I,J,K)=POD(I,J,K)	00081500
210 CONTINUE	00081600
	00081700
C *** FOLLOWING IS FOR DETERMINING THE THERMOCOUPLE POSITIONS	00081800
	00081900
DO 5000 N=1,NTHCO	00082000
DO 5001 I=1,NIP1	00082100
IF (XC(I).LT.CX(N).AND.XC(I-1).GE.CX(N)) GOTO 5002	00082200
5001 CONTINUE	00082300
5002 II=I	00082400
	00082500

```

DO 5003 J=1,NJP1
IF (YC(J).LT.CY(N).AND.YC(J+1).GE.CY(N)) GOTO 5004
5003 CONTINUE
5004 JJ=J

DO 5005 K=1,NKP1
IF (ZC(K).LT.CZ(N).AND.ZC(K+1).GE.CZ(N)) GOTO 5006
5005 CONTINUE
5006 KK=K
NTH(N,1)=II
NTH(N,2)=JJ
NTH(N,3)=KK
5000 CONTINUE

RETURN
END

C ***
C *****
SUBROUTINE CALVIS
C *****
C *** THIS SUBROUTINE CALCULATES THE TURBULENT VISCOSITY AND UPDATES*
* THE VISCOSITY MATRIX *
*****

COMMON/R4/XC(93),YC(93),ZC(93),XS(93),YS(93),ZS(93),
& DXXC(93),DYXC(93),DZXC(93),DXXS(93),DYYS(93),DZZS(93)
COMMON/BL7/NI,NIP1,NIM1,NJ,NJP1,NJM1,NK,NKP1,NKM1
& ,NIP2,NJP2,NKP2,NA,NAP1,NAM1,NB,NBP1,NBM1,KRUN,NCHIP,NJRA,NWRP
COMMON/BL14/HCOEF,TINF,CNT,ABTURB,BTURB,VISL,VISMAX,QCORRT,PM1,PM2000
COMMON/BL16/CONST1,CONST2,CONST3,CONST4,CONST6,NT,UO,H,UGRT,BUOY,
& CPO,PRT,CONDO,VISO,RHOO,HR,TR,TA,DTEMP,TWRITE,TTAPE,TMAX,GC,RAIROO
COMMON/BL32/ T(22,16,32),R(22,16,32),P(22,16,32)
& ,C(22,16,32),U(22,16,32),V(22,16,32),W(22,16,32)
COMMON/BL34/ HEIGHT(22,16,32),REQ(22,16,32),
& SMP(22,16,32),SMPP(22,16,32),PP(22,16,32),
& DU(22,16,32),DV(22,16,32),DW(22,16,32)
COMMON/BL36/AP(22,16,32),AE(22,16,32),AW(22,16,32),AN(22,16,32),
& AS(22,16,32),AF(22,16,32),AB(22,16,32),
& SP(22,16,32),SU(22,16,32),RI(22,16,32)
COMMON/BL37/ VIS(22,16,32),COND(22,16,32),NOD(22,16,32),RWALL(579)
& ,CPM(22,16,32),HSZ(3,2),NHSZ(22,16,32),RESORM(93)

C *** CALCULATE LOCAL SHEAR AND VISCOSITY VIS(I,J,K)
C
C *** SPECIFY LOCAL TURBULENT LENGTH SCALES SMPP(I,J,K)

DO 611 K=2,NK
KP2=K+2
KP1=K+1
KM1=K-1
KM2=K-2
DO 611 J=2,NJ
JP2=J+2
JP1=J+1
JM1=J-1
JM2=J-2
DO 611 I=2,NI
IP2=I+2
IP1=I+1
IM1=I-1
IM2=I-2
IF (I.EQ.2) IM2=NIM1
IF (I.EQ.NI) IP2=3
IF (NOD(I,J,K).EQ.1) GOTO 611

```

C	CENTRAL LENGTH OF THE SCALE CONTROL VOLUME	00089400
	DXP1=XL(IP1,J,K,0,0)	00089500
	DXI =XL(I ,J,K,0,0)	00089600
	DXM1=XL(IM1,J,K,0,0)	00089700
		00089800
		00089900
		00090000
	DYP1=YL(I,JP1,K,0,0)	00090100
	DYJ =YL(I,J ,K,0,0)	00090200
	DYM1=YL(I,JM1,K,0,0)	00090300
		00090400
	DZP1=ZL(I,J,KP1,0,0)	00090500
	DZK =ZL(I,J,K ,0,0)	00090600
	DZM1=ZL(I,J,KM1,0,0)	00090700
		00090800
CC	IF (J.EQ.2) DYS=DYS/2.	00090900
CC	IF (K.EQ.2) DZB=DZB/2.	00091000
	IF (J.NE.NJ) GOTO 101	00091100
	JP2=JP1	00091200
	DYN=DYN/2.	00091300
101	IF (K.NE.NK) GOTO 102	00091400
	KP2=KP1	00091500
	DZF=DZF/2.	00091600
102	CONTINUE	00091700
		00091800
C ***	CENTRAL LENGTH OF THE STAGGERED CONTROL VOLUME FOR T	00091900
	DXE =XL(IP1,J,K,0,1)	00092000
	DXW =XL(I ,J,K,0,1)	00092100
		00092200
	DYN =YL(I,JP1,K,0,2)	00092300
	DYS =YL(I,J ,K,0,2)	00092400
		00092500
	DZF =ZL(I,J,KP1,0,3)	00092600
	DZB =ZL(I,J,K ,0,3)	00092700
		00092800
		00092900
C ***	CACULATE DV/DX,D2V/DX2,DU/DX,D2U/DX2,DW/DX AND D2W/DX2	00093000
		00093100
		00093200
	DUDX=(U(IP1,J,K)-U(I,J,K))/DXI	00093300
	DUDXW=0.5*(U(IP1,J,K)-U(IM1,J,K))/DXW	00093400
	DUDXE=0.5*(U(IP2,J,K)-U(I ,J,K))/DXE	00093500
	D2UDX2=(DUDXE-DUDXW)/DXI	00093600
		00093700
		00093800
	DVDXW=0.5*(V(I,JP1,K)-V(I,J,K)-V(IM1,JP1,K)-V(IM1,J,K))/DXW	00093900
	DVDXE=0.5*(V(IP1,JP1,K)-V(IP1,J,K)-V(I,JP1,K)-V(I,J,K))/DXE	00094000
	DVDX=0.5*(DVDXE+DVDXW)	00094100
	D2VDX2=(DVDXE-DVDXW)/DXI	00094200
		00094300
		00094400
	DWDXW=0.5*(W(I,J,KP1)-W(I,J,K)-W(IM1,J,KP1)-W(IM1,J,K))/DXW	00094500
	DWDXE=0.5*(W(IP1,J,KP1)+W(IP1,J,K)-W(I,J,KP1)-W(I,J,K))/DXE	00094600
	DWDX=0.5*(DWDXE-DWDXW)	00094700
	D2WDX2=(DWDXE-DWDXW)/DXI	00094800
		00094900
		00095000
		00095100
		00095200
C ***	CALCULATE DU/DY,D2U/DY2,DV/DY,D2V/DY2,DW/DY AND D2W/DY2	00095300
		00095400
		00095500
	DVDY=(V(I,JP1,K)-V(I,J,K))/DYJ	00095600
	DVDYS=0.5*(V(I,JP1,K)-V(I,JM1,K))/DYS	00095700
	DVDYN=0.5*(V(I,JP2,K)-V(I,J ,K))/DYN	00095800
	D2VDY2=(DVDYN-DVDYS)/DYJ	00095900
		00096000
		00096100

```

DUDYS=C.5*(U(IP1,J,K)+U(I,J,K)-U(IP1,JM1,K)-U(I,JM1,K))/DYS
DUDYN=C.5*(U(IP1,JP1,K)+U(I,JP1,K)-U(IP1,J,K)-U(I,J,K))/DYN
DUDY=C.5*(DUDYN+DUDYS)
D2UDY2=(DUDYN-DUDYS)/DYJ

```

```

DWDYS=C.5*(W(I,J,KP1)+W(I,J,K)-W(I,JM1,KP1)-W(I,JM1,K))/DYS
DWDYN=C.5*(W(I,JP1,KP1)+W(I,JP1,K)-W(I,J,KP1)-W(I,J,K))/DYN
DWDY=C.5*(DWDYN+DWDYS)
D2WDY2=(DWDYN-DWDYS)/DYJ

```

606 CONTINUE

C *** CALCULATE DU/DZ, D2U/DZ2, DV/DZ, D2V/DZ2, DW/DZ AND D2W/DZ2

```

DWDZ=(W(I,J,KP1)-W(I,J,K))/DZK
DWDZF=C.5*(W(I,J,KP2)-W(I,J,K))/DZF
DWDZB=C.5*(W(I,J,KP1)-W(I,J,KM1))/DZB
D2WDZ2=(DWDZF-DWDZB)/DZK

```

```

DVDZB=C.5*(V(I,JP1,K)+V(I,J,K)-V(I,JP1,KM1)-V(I,J,KM1))/DZB
DVDZF=C.5*(V(I,JP1,KP1)+V(I,J,KP1)-V(I,JP1,K)-V(I,J,K))/DZF
DVDZ=C.5*(DVDZF+DVDZB)
D2VDZ2=(DVDZF-DVDZB)/DZK

```

```

DUDZB=C.5*(U(IP1,J,K)+U(I,J,K)-U(IP1,J,KM1)-W(I,J,KM1))/DZB
DUDZF=C.5*(U(IP1,J,KP1)+U(I,J,KP1)-U(IP1,J,K)-U(I,J,K))/DZF
DUDZ=C.5*(DUDZF+DUDZB)
D2UDZ2=(DUDZF-DUDZB)/DZK

```

```

DRDX=((R(IP1,J,K)-REQ(IP1,J,K))-(R(IM1,J,K)-REQ(IM1,J,K)))/
& (DXE-DXW)
DRDY=((R(I,JP1,K)-REQ(I,JP1,K))-(R(I,JM1,K)-REQ(I,JM1,K)))/
& (DYN-DYS)
DRDZ=((R(I,J,KP1)-REQ(I,J,KP1))-(R(I,J,KM1)-REQ(I,J,KM1)))/
& (DZF-DZB)
& DRDGA=SIN(ZC(K))*(SIN(XC(I))*DRDY+COS(XC(I))*DRDX)
& -COS(ZC(K))*DRDZ

```

C *** CALCULATE RICHARDSON NUMBER

```

STRAIN=DUDY**2+DUDX**2+DWDX**2+DVDZ**2+DWDY**2+DUDZ**2
DDO2 = SQRT(DUDY*DUDY+DUDX*DUDX+DUDZ*DUDZ+DUDY*DUDY+DUDX*DUDX+
& DVDZ*DVDZ+DWDX*DWDX+DWDY*DWDY+DWDZ*DWDZ)
IF(DDO2.EQ.0.)GO TO 600

```

C *** CALCULATE TURBULENT LENGTH SCALE SMPP(I,J)

```

SMPP123=SQRT(((U(IP1,J,K)+U(I,J,K))*0.5)**2+((V(I,JP1,K)-V(I,J,K))
& 0.5)**2+((W(I,J,KP1)+W(I,J,K))*0.5)**2)/DDO2
SMPP12=DDO2 /SQRT(D2UDX2+D2UDX2+D2UDY2+D2UDY2
& -D2UDZ2+D2UDZ2+D2VDX2+D2VDX2+D2VDY2+D2VDY2+D2VDZ2+D2VDZ2+
& D2WDZ2+D2WDZ2+D2WDX2+D2WDX2+D2WDY2+D2WDY2)
SMPP(I,J,K)=CNT*(SMPP123+SMPP12)*.5
RI(I,J,K)=-BUOY*DRDGA/(R(I,J,K)*STRAIN)
ABRIPR=ABTURB+RI(I,J,K)/PRT
IF(ABRIPR.LT. 0.) GO TO 600
IF(ABRIPR.EQ. 0.) GO TO 613
GO TO 610
600 VIS(I,J,K)=VISL
GO TO 611
613 VIS(I,J,K)=VISMAX
GO TO 611
610 VIS(I,J,K)=VISL+R(I,J,K)*SMPP(I,J,K)*SMPP(I,J,K)*SQRT(STRAIN)/
& (BTURB+ABRIPR)

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IF(VIS(I,J,K) .GT. VISMAL) VIS(I,J,K)=VISMAL
611 CONTINUE

DO 110 I=1,NIP1
DO 110 J=1,NJP1
VIS(I,J,NKP1)=VIS(I,J,NK)
VIS(I,J,1)=VIS(I,J,2)
110 CONTINUE

DO 120 J=1,NJP1
DO 120 K=1,NKP1
VIS(NIP1,J,K)=VIS(2,J,K)
VIS(1,J,K)=VIS(NI,J,K)
120 CONTINUE

DO 130 K=1,NKP1
DO 130 I=1,NIP1
VIS(I,NJP1,K)=VIS(I,NJ,K)
VIS(I,2,K)=VIS(I,3,K)
VIS(I,1,K)=VIS(I,2,K)
130 CONTINUE

DO 135 K=1,16
KK=NKP1-K
DO 135 I=1,NIP1
DO 135 J=1,NJP1
VIS(I,J,KK)=VIS(I,J,K)
135 CONTINUE

DO 140 I=1,NIP1
DO 140 J=1,NJP1
DO 140 K=1,NKP1
IF (MOD(I,J,K).EQ.1) GOTO 140
COND(I,J,K)=VIS(I,J,K)/PRT
140 CONTINUE

RETURN
END

C
C
C SUBROUTINE CALT
C
COMMON/R4/XC(93),YC(93),ZC(93),XS(93),YS(93),ZS(93),
6 DXXC(93),DYXC(93),DZZC(93),DXXS(93),DYXS(93),DZZS(93)
COMMON/BL1/DX,DY,DZ,VOL,DTIME,VOLDT,THOT,TCCOL,PI,Q,QR
COMMON/BL7/N1,NIP1,NIM1,NJ,NJP1,NJM1,NK,NKP1,NKM1
6 ,NIP2,NJP2,NKP2,NA,NAP1,NAM1,NB,NBP1,NBM1,KRUN,NCHIP,NJRA,NWRP
COMMON/BL12/NWRITE,NTAPE,NTMAXO,NTREAL,TIME,SORSUM,ITER
COMMON/BL14/HCOEF,TINF,CNT,ABTURB,BTURB,VISL,VISMAL,QCORRT,PM1,PM200107400
COMMON/BL16/CONST1,CONST2,CONST3,CONST4,CONST6,NT,UG,H,UGRT,BUOY,00107500
6 CPS,PRT,CONDO,VISO,RHOO,HR,TR,TA,DTEMP,TWRITE,TTAPE,TMAX,GC,RAIROO107600
COMMON/BL22/1CHPB(10),NCHPI(10),JCHPB(10),NCHPJ(10),KCHPB(10),
6 NCHPK(10),TCHP(10),CPS(10),CONS(10),WFAN(10)
COMMON/BL31/TOD(22,16,32),ROD(22,16,32),POD(22,16,32)
6 ,COD(22,16,32),UOD(22,16,32),VOD(22,16,32),WOD(22,16,32)
COMMON/BL32/T(22,16,32),R(22,16,32),P(22,16,32)
6 ,C(22,16,32),U(22,16,32),V(22,16,32),W(22,16,32)
COMMON/BL33/TPD(22,16,32),RPD(22,16,32),PPD(22,16,32)
6 ,CPD(22,16,32),UPD(22,16,32),VPD(22,16,32),WPD(22,16,32)
COMMON/BL34/HEIGHT(22,16,32),REQ(22,16,32),
6 SMP(22,16,32),SMPP(22,16,32),PP(22,16,32),
6 DV(22,16,32),DW(22,16,32)
COMMON/BL36/AP(22,16,32),AE(22,16,32),AW(22,16,32),AN(22,16,32),
6 AS(22,16,32),AF(22,16,32),AB(22,16,32),

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4	SP(22,16,32),SU(22,16,32),RI(22,16,32)	00090000
	COMMON/BL37/VIS(22,16,32),COND(22,16,32),NOD(22,16,32),RWALL(579)	00109100
4	,CPM(22,16,32),HSZ(3,2),NHSZ(22,16,32),RESORM(93)	00109200
		00109300
C ***	CALCULATE COEFFICIENTS	00109400
	DO 100 K=2,NK	00109500
	KP2=K+2	00109600
	KP1=K+1	00109700
	KM1=K-1	00109800
	KM2=K-2	00109900
	DO 100 J=2,NJ	00110000
	JP2=J+2	00110100
	JP1=J+1	00110200
	JM1=J-1	00110300
	JM2=J-2	00110400
	DO 100 I=2,NI	00110500
	IP2=I+2	00110600
	IP1=I+1	00110700
	IM1=I-1	00110800
	IM2=I-2	00110900
	IF (I.EQ.2) IM2=NIM1	00111000
	IF (I.EQ.NI) IP2=3	00111100
		00111200
C	CENTRAL LENGTH OF THE TEMPERATURE CONTROL VOLUME	00111300
	DXP1=XL(IP1,J,K,0,0)	00111400
	DXI =XL(I ,J,K,0,0)	00111500
	DXM1=XL(IM1,J,K,0,0)	00111600
		00111700
	DYP1=YL(I,JP1,K,0,0)	00111800
	DYJ =YL(I,J ,K,0,0)	00111900
	DYM1=YL(I,JM1,K,0,0)	00112000
		00112100
	DZP1=ZL(I,J,KP1,0,0)	00112200
	DZK =ZL(I,J,K ,0,0)	00112300
	DZM1=ZL(I,J,KM1,0,0)	00112400
		00112500
		00112600
		00112700
C ***	SURFACE LENGTH OF THE CONTROL VOLUME	00112800
	DXN=XL(I,JP1,K,0,2)	00112900
	DXS=XL(I,J ,K,0,2)	00113000
	DXF=XL(I,J,KP1,0,3)	00113100
	DXB=XL(I,J,K ,0,3)	00113200
		00113300
	DYF=YL(I,J,KP1,0,3)	00113400
	DYB=YL(I,J,K ,0,3)	00113500
	DYE=YL(IP1,J,K,0,1)	00113600
	DYN=YL(I ,J,K,0,1)	00113700
		00113800
	DZE=ZL(IP1,J,K,0,1)	00113900
	DZW=ZL(I ,J,K,0,1)	00114000
	DZN=ZL(I,JP1,K,0,2)	00114100
	DZS=ZL(I,J ,K,0,2)	00114200
		00114300
		00114400
C ***	CENTRAL LENGTH OF THE STAGGERED CONTROL VOLUME FOR T	00114500
	DXEE=XL(IP2,J,K,0,1)	00114600
	DXE =XL(IP1,J,K,0,1)	00114700
	DXW =XL(I ,J,K,0,1)	00114800
	DXWW=XL(IM1,J,K,0,1)	00114900
		00115000
	DYNN=YL(I,JP2,K,0,2)	00115100
	DYN =YL(I,JP1,K,0,2)	00115200
	DYS =YL(I,J ,K,0,2)	00115300
	DYSS=YL(I,DX1,K,0,2)	00115400
		00115500
		00115600
	DZFF=ZL(I,J,KP2,0,3)	00115700

DZF =ZL(I,J,KP1,0,3)
 DZB =ZL(I,J,K,0,3)
 DZBB=ZL(I,J,KM1,0,3)

C *** DEFINE THE AREA OF THE CONTROL VOLUME

DXYF=DXF*DYF
 DXYB=DXB*DYB
 DYZE=DYE*DZE
 DYZW=DYW*DZW
 DZKN=DZN*DXN
 DZXS=DZS*DXS

VOL=DXI*DYJ*DZK
 VOLDT=VOL/DTIME

ZXOYN=DZKN/DYN
 ZXOYS=DZKS/DYS
 XYOZF=DXYF/DZF
 XYOZB=DXYB/DZB
 YZOXE=DYZE/DXE
 YZOXW=DYZW/DXW

GN=(R(I,J,K)*DYP1+R(I,JP1,K)*DYJ)/(DYP1+DYJ)
 GS=(R(I,J,K)*DYM1+R(I,JM1,K)*DYJ)/(DYM1+DYJ)
 GE=(R(I,J,K)*DXP1+R(IP1,J,K)*DXI)/(DXP1+DXI)
 GW=(R(I,J,K)*DXM1+R(IM1,J,K)*DXI)/(DXM1+DXI)
 GF=(R(I,J,K)*DZP1+R(I,J,KP1)*DZK)/(DZP1+DZK)
 GB=(R(I,J,K)*DZM1+R(I,J,KM1)*DZK)/(DZM1+DZK)

CN=GN*V(I,JP1,K)*DZKN
 CS=GS*V(I,J,K)*DZKS
 CE=GE*V(IP1,J,K)*DYZE
 CW=GW*V(I,J,K)*DYZW
 CF=GF*V(I,J,KP1)*DXYF
 CB=GB*V(I,J,K)*DXYB

CONDN=1./((1./COND(I,J,K)*DYJ+1./COND(I,JP1,K)*DYP1)/(DYP1-DYJ))
 CONDS=1./((1./COND(I,J,K)*DYJ+1./COND(I,JM1,K)*DYM1)/(DYM1+DYJ))
 CONDE=1./((1./COND(I,J,K)*DXI+1./COND(IP1,J,K)*DXP1)/(DXP1+DXI))
 CONDW=1./((1./COND(I,J,K)*DXI+1./COND(IM1,J,K)*DXM1)/(DXM1+DXI))
 CONDF=1./((1./COND(I,J,K)*DZK+1./COND(I,J,KP1)*DZP1)/(DZP1+DZK))
 CONDB=1./((1./COND(I,J,K)*DZK+1./COND(I,J,KM1)*DZM1)/(DZM1+DZK))

CONDN*=ZXOYN*CONDN
 CONDS*=ZXOYS*CONDS
 CONDE*=YZOXE*CONDE
 CONDW*=YZOXW*CONDW
 CONDF*=XYOZF*CONDF
 CONDB*=XYOZB*CONDB

CEP=(ABS(CE)+CE)*DXP1*DXI/(DXE*(DXE+DXW))/8.
 CEM=(ABS(CE)-CE)*DXP1*DXI/(DXE*(DXE+DXE))/8.
 CWP=(ABS(CW)+CW)*DXM1*DXI/(DXW*(DXW+DXW))/8.
 CWM=(ABS(CW)-CW)*DXM1*DXI/(DXW*(DXW+DXE))/8.

CNP=(ABS(CN)+CN)*DYP1*DYJ/(DYN*(DYN+DYS))/8.
 CNM=(ABS(CN)-CN)*DYP1*DYJ/(DYN*(DYN+DYN))/8.
 CSP=(ABS(CS)+CS)*DYM1*DYJ/(DYS*(DYS+DYS))/8.
 CSM=(ABS(CS)-CS)*DYM1*DYJ/(DYS*(DYS+DYN))/8.

CFP=(ABS(CF)+CF)*DZP1*DZK/(DZF*(DZF-DZB))/8.
 CFM=(ABS(CF)-CF)*DZP1*DZK/(DZF*(DZF-DZFF))/8.
 CBP=(ABS(CB)-CB)*DZM1*DZK/(DZB*(DZB+DZBB))/8.
 CBM=(ABS(CB)-CB)*DZM1*DZK/(DZB*(DZB+DZF))/8.

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AE(I,J,K) = -.5*DXI/DXE*CE+CEP+CEM*(1.+DXE/DXEE)+CWM*DXW/DXE	00123198
AW(I,J,K) = .5*DXI/DXW*CW+CWM+CWP*(1.+DXW/DXWW)+CEP*DXE/DXW	00123199
AN(I,J,K) = -.5*DYJ/DYN*CN+CNP+CNM*(1.+DYN/DYNN)+CSM*DYS/DYN	00123200
AS(I,J,K) = .5*DYJ/DYS*CS+CSM+CSP*(1.+DYS/DYSS)+CNP*DYN/DYS	00123201
AF(I,J,K) = -.5*DZK/DZF*CF+CFP+CFM*(1.+DZF/DZFF)+CBM*DZB/DZF	00123202
AB(I,J,K) = .5*DZK/DZB*CB+CBM+CBP*(1.+DZB/DZBB)+CFP*DZF/DZB	00123203
C	00123204
801 AEE=-CEM*DXE/DXEE	00123210
AEER=AEE*TPD(IP2,J,K)*CPM(IP2,J,K)	00123300
802 CONTINUE	00123400
	00123500
803 ANW=-CWP*DXW/DXWW	00123600
ANWR=ANW*TPD(IM2,J,K)*CPM(IM2,J,K)	00123700
804 CONTINUE	00123800
	00123900
IF (J.LT.NJ) GOTO 805	00124000
ANN=0.	00124100
ANNR=0.	00124200
GOTO 806	00124300
805 ANN=-CNM*DYN/DYNN	00124400
ANNR=ANN*TPD(I,JP2,K)*CPM(I,JP2,K)	00124500
806 CONTINUE	00124600
	00124700
IF (J.GT.2) GOTO 807	00124800
ASS=0.	00124900
ASSR=0.	00125000
GOTO 808	00125100
807 ASS=-CSP*DYS/DYSS	00125200
ASSR=ASS*TPD(I,JM2,K)*CPM(I,JM2,K)	00125300
808 CONTINUE	00125400
	00125500
IF (K.LT.NK) GOTO 809	00125600
AFF=0.	00125700
AFFR=0.	00125800
GOTO 810	00125900
809 AFF=-CFM*DZF/DZFF	00126000
AFFR=AFF*TPD(I,J,KP2)*CPM(I,J,KP2)	00126100
810 CONTINUE	00126200
	00126300
IF (K.GT.2) GOTO 811	00126400
ABB=0.	00126500
ABBR=0.	00126600
GOTO 812	00126700
811 ABB=-CBP*DZB/DZBB	00126800
ABBR=ABB*TPD(I,J,KM2)*CPM(I,J,KM2)	00126900
812 CONTINUE	00127000
	00127100
	00127200
	00127300
C *****	00127400
C *****	00127500
C *** MODIFICATION FOR DECK BOUNDARIES	00127600
	00127700
900 CONTINUE	00127800
IF (MOD(IM1,J,K).EQ.0) GOTO 901	00127900
ANW=0.0	00128000
ANWR=0.0	00128100
	00128200
901 CONTINUE	00128300
IF (MOD(IP1,J,K).EQ.0) GOTO 902	00128400
AEE=0.0	00128500
AEER=0.0	00128600
	00128700
902 CONTINUE	00128800
IF (MOD(I,JM1,K).EQ.0) GOTO 903	00128900
ASS=0.0	00129000
ASSR=0.0	00129100
	00129200

903	CONTINUE	00129300
	IF (MOD(I,JP1,K).EQ.0) GOTO 904	00129400
	ANN=0.0	00129500
	ANNR=0.0	00129600
		00129700
904	CONTINUE	00129800
	IF (MOD(I,J,KM1).EQ.0) GOTO 905	00129900
	ABB=0.0	00130000
	ABBR=0.0	00130100
		00130200
905	CONTINUE	00130300
	IF (MOD(I,J,KP1).EQ.0) GOTO 906	00130400
	AFF=0.0	00130500
	AFFR=0.0	00130600
		00130700
906	CONTINUE	00130800
		00130900
C	*****	00131000
C	*****	00131100
		00131200
	AP(I,J,K)=(AE(I,J,K)+AW(I,J,K)+AN(I,J,K)+AS(I,J,K)	00131300
	& +AF(I,J,K)+AB(I,J,K)+AEE+AWW+ANN+ASS+AFF+ABB)*CPM(I,J,K)	00131400
	& +CONDE1+CONDW1+CONDN1+CONDS1+CONDF1+CONDB1	00131500
		00131600
	AE(I,J,K)=AE(I,J,K)*CPM(IP1,J,K)+CONDE1	00131700
	AW(I,J,K)=AW(I,J,K)*CPM(IM1,J,K)+CONDW1	00131800
	AN(I,J,K)=AN(I,J,K)*CPM(I,JP1,K)+CONDN1	00131900
	AS(I,J,K)=AS(I,J,K)*CPM(I,JM1,K)+CONDS1	00132000
	AF(I,J,K)=AF(I,J,K)*CPM(I,J,KP1)+CONDF1	00132100
	AB(I,J,K)=AB(I,J,K)*CPM(I,J,KM1)+CONDB1	00132200
		00132300
	SP(I,J,K)=-ROD(I,J,K)*VOLDT*CPM(I,J,K)	00132400
	SU(I,J,K)=ROD(I,J,K)*VOLDT*TOD(I,J,K)*CPM(I,J,K)	00132500
	SU(I,J,K)=SU(I,J,K)+AEER+AWWR+ANNR+ASSR+AFFR+ABBR	00132600
100	CONTINUE	00132700
		00132800
C	*** TAKE CARE OF B.C. THRU AN,AS,AE,AW,AF,AB,SP AND SU	00132900
		00133000
C	*** RADIUS DIRECTION	00133100
		00133200
	DO 500 I=2,NI	00133300
	DO 500 K=2,NK	00133400
	SP(I,2,K)=SP(I,2,K)-AS(I,2,K)	00133500
CC	SP(I,2,K)=SP(I,2,K)-AS(I,2,K)	00133600
CC	SU(I,2,K)=SU(I,2,K)+2.0*AS(I,2,K)*TPD(I,1,K)	00133700
	SP(I,NJ,K)=SP(I,NJ,K)-AN(I,NJ,K)	00133800
	SU(I,NJ,K)=SU(I,NJ,K)+2.*TPD(I,NJP1,K)*AN(I,NJ,K)	00133900
	AS(I,2,K)=0.	00134000
	AN(I,NJ,K)=0.	00134100
500	CONTINUE	00134200
		00134300
C	*** CYLIC CONDITIONS	00134400
		00134500
	DO 600 J=2,NJ	00134600
	DO 600 K=2,NK	00134700
	SU(2,J,K)=SU(2,J,K)+AW(2,J,K)*T(1,J,K)	00134800
	SU(NI,J,K)=SU(NI,J,K)+AE(NI,J,K)*T(NIP1,J,K)	00134900
	AW(2,J,K)=0.0	00135000
	AE(NI,J,K)=0.0	00135100
600	CONTINUE	00135200
		00135300
C	*** END OF SPHERE	00135400
		00135500
	DO 700 I=2,NI	00135600
	DO 700 J=2,NJ	00135700
	SP(I,J,2)=SP(I,J,2)-AB(I,J,2)	00135800
	SP(I,J,NK)=SP(I,J,NK)-AF(I,J,NK)	00135900
	AB(I,J,2)=0.	00136000

AF(I,J,NK)=0.	00136100
700 CONTINUE	00136200
	00136300
C *** ASSEMBLE COEFFICIENTS AND SOLVE DIFFERENCE EQUATIONS	00136400
	00136500
DO 300 K=2,NK	00136600
DO 300 J=2,NJ	00136700
DO 300 I=2,NI	00136800
AP(I,J,K)=AP(I,J,K)-SP(I,J,K)	00136900
300 CONTINUE	00137000
	00137100
	00137200
	00137300
	00137400
C *** VOLUME HEAT SOURCE INPUT	00137500
	00137600
VOLT=0.0	00137700
DO 113 I=2,NI	00137800
DO 113 J=2,NJ	00137900
DO 113 K=16,17	00138000
IF (NHSZ(I,J,K).EQ.0) GOTO 113	00138100
DXI =XL(I,J,K,0,0)	00138200
DYJ =YL(I,J,K,0,0)	00138300
DZK =ZL(I,J,K,0,0)	00138400
VOL=DXI*DYJ*DZK*H*H*H	00138500
VOLT=VOLT+VOL	00138600
113 CONTINUE	00138700
	00138800
DO 111 I=2,NI	00138900
DO 111 J=2,NJ	00139000
DO 111 K=16,17	00139100
IF (NHSZ(I,J,K).EQ.0) GOTO 111	00139200
DXI =XL(I,J,K,0,0)	00139300
DYJ =YL(I,J,K,0,0)	00139400
DZK =ZL(I,J,K,0,0)	00139500
QQQ=Q*H/(UO*CPO*RHOO*TA)	00139600
VOL=DXI*DYJ*DZK	00139700
SU(I,J,K)=SU(I,J,K)+VOL*QQQ/VOLT	00139800
111 CONTINUE	00139900
	00140000
	00140100
C *** RADIATION INTO THE WALL	00140200
	00140300
C DO 310 K=3,NKMI	00140400
C DO 310 I=2,NI	00140500
C DXN =XL(I,NJRA,K,0,2)	00140501
C DZN =ZL(I,NJRA,K,0,2)	00140503
C DZKN=DZN*DXN	00140504
C II=(K-3)*(NI-1)+I-1	00140600
C SU(I,NJRA,K)=SU(I,NJRA,K)-RWALL(II)*DZKN	00140700
C 310 CONTINUE	00140800
	00140900
C *** END OF RADIATION	00141000
	00141100
C *** SOLVE FOR T	00141200
write(6,*) 'calling trid'	
00141300	
CALL TRID (2,2,2,NI,NJ,NK,T)	00141400
	00141500
C ***** RESET TEMPERATURE AT R=0.0 AND END OF SPHERE	00141600
	00141700
DO 81 K=1,NKP1	00141800
AVT=0.0	00141900
DO 82 I=2,NI	00142000
AVT=AVT-(T(I,2,K)/NIM1)	00142100
82 CONTINUE	00142200
DO 83 I=1,NIP1	00142300
T(I,1,K)=AVT	00142400

83	CONTINUE	00142500
81	CONTINUE	00142600
C		00142700
	DO 74 I=1,NIP1	00142800
	DO 74 J=1,NJP1	00142900
	T(I,J,1)=T(I,J,2)	00143000
	T(I,J,NKP1)=T(I,J,NK)	00143100
74	CONTINUE	00143200
C ***	FOR SURFACE HEAT EXCHANGE WITH SURROUNDING	00143300
	DO 84 I=2,NI	00143400
	DO 84 K=2,NK	00143500
	DYJ=YL(I,NJ,K,0,0)	00143600
	T(I,NJP1,K)=(2.0*COND(I,NJ,K)*T(I,NJ,K)/DYJ+HCOEF*TINF)/	00143700
	(HCOEF+2.0*COND(I,NJ,K)/DYJ)	00143800
84	CONTINUE	00143900
		00144000
		00144300
		00144400
		00144500
C ***	FOR CYLIC CONDITION	00144600
	DO 80 J=1,NJP1	00144700
	DO 80 K=1,NKP1	00144800
	T(1,J,K)=T(NI,J,K)	00144900
	T(NIP1,J,K)=T(2,J,K)	00145000
80	CONTINUE	00145100
		00145200
		00145300
	RETURN	00145400
	END	00145500
		00145600
		00145700
		00145800
C		00145900
C ***	*****	00146000
	SUBROUTINE CALC	00146100
C ***	*****	00146200
	COMMON/R4/XC(93),YC(93),ZC(93),XS(93),YS(93),ZS(93),	00146300
	DXXC(93),DYXC(93),DZXC(93),DXXS(93),DYXS(93),DZZS(93)	00146400
	COMMON/BL1/DX,DY,DZ,VOL,DTIME,VOLDT,THOT,TCOOL,PI,Q,QR	00146500
	COMMON/BL7/NI,NIP1,NIM1,NJ,NJP1,NJM1,NK,NKP1,NKM1	00146600
	,NIP2,NJP2,NKP2,NA,NAP1,NAM1,NB,NBP1,NBM1,KRUN,NCHIP,NJRA,NWRP	00146700
	COMMON/BL12/NWRITE,NTAPE,NTMAXO,NTREAL,TIME,SORSUM,ITER	00146800
	COMMON/BL14/HCOEF,TINF,CNT,ABTURB,BTURB,VISL,VISMAX,QCORRT,PM1,PM200146900	00146900
	COMMON/BL16/CONST1,CONST2,CONST3,CONST4,CONST6,NT,UO,H,UGRT,BUOY,00147000	00147000
	,CPO,PRT,CONDO,VISO,RHOO,HR,TR,TA,DTEMP,TWRITE,TTAPE,TMAX,GC,RAIR00147100	00147100
	COMMON/BL22/TCHPB(10),NCHPI(10),JCHPB(10),NCHPJ(10),KCHPB(10),	00147200
	NCHPK(10),TCHP(10),CPS(10),CONS(10),WFAN(10)	00147300
	COMMON/BL31/TOD(22,16,32),ROD(22,16,32),POD(22,16,32)	00147400
	,COD(22,16,32),UOD(22,16,32),VOD(22,16,32),WOD(22,16,32)	00147500
	COMMON/BL32/T(22,16,32),R(22,16,32),P(22,16,32)	00147600
	,C(22,16,32),U(22,16,32),V(22,16,32),W(22,16,32)	00147700
	COMMON/BL33/TPD(22,16,32),RPD(22,16,32),PPD(22,16,32)	00147800
	,CPD(22,16,32),UPD(22,16,32),VPD(22,16,32),WPD(22,16,32)	00147900
	COMMON/BL34/HEIGHT(22,16,32),REQ(22,16,32),	00148000
	SMP(22,16,32),SMPP(22,16,32),PP(22,16,32),	00148100
	DU(22,16,32),DV(22,16,32),DW(22,16,32)	00148200
	COMMON/BL36/AP(22,16,32),AE(22,16,32),AW(22,16,32),AN(22,16,32),	00148300
	AS(22,16,32),AF(22,16,32),AB(22,16,32),	00148400
	SP(22,16,32),SU(22,16,32),RI(22,16,32)	00148500
	COMMON/BL37/VIS(22,16,32),COND(22,16,32),NOD(22,16,32),RWALL(579)	00148600
	,CPM(22,16,32),HSZ(3,2),NHSZ(22,16,32),RESORM(93)	00148700
	COMMON/BL39/ALEW,PCURVE,CONSRA,PCURM1,PSOUTH,QCORR,PEROR	00148800
		00148900
C ***	CALCULATE COEFFICIENTS	00149000
	DO 100 K=2,NK	00149100
	KP2=K-2	00149200
	KP1=K-1	00149300
		00149400

KM1=K-1	00149500
KM2=K-2	00149600
DO 100 J=2,NJ	00149700
JP2=J+2	00149800
JP1=J+1	00149900
JM1=J-1	00150000
JM2=J-2	00150100
DO 100 I=2,NI	00150200
IP2=I-2	00150300
IP1=I-1	00150400
IM1=I-1	00150500
IM2=I-2	00150600
IF (I.EQ.2) IM2=NIM1	00150700
IF (I.EQ.NI) IP2=3	00150800
C CENTRAL LENGTH OF THE SCALE CONTROL VOLUME	00150900
DXP1=XL(IP1,J,K,0,0)	00151000
DXI =XL(I ,J,K,0,0)	00151100
DXM1=XL(IM1,J,K,0,0)	00151200
DYP1=YL(I,JP1,K,0,0)	00151300
DYJ =YL(I,J ,K,0,0)	00151400
DYM1=YL(I,JM1,K,0,0)	00151500
DZP1=ZL(I,J,KP1,0,0)	00151600
DZK =ZL(I,J,K ,0,0)	00151700
DZM1=ZL(I,J,KM1,0,0)	00151800
C *** SURFACE LENGTH OF THE CONTROL VOLUME	00151900
DXN=XL(I,JP1,K,0,2)	00152000
DXS=XL(I,J ,K,0,2)	00152100
DXF=XL(I,J,KP1,0,3)	00152200
DXB=XL(I,J,K ,0,3)	00152300
DYF=YL(I,J,KP1,0,3)	00152400
DYB=YL(I,J,K ,0,3)	00152500
DYE=YL(IP1,J,K,0,1)	00152600
DYW=YL(I ,J,K,0,1)	00152700
DZE=ZL(IP1,J,K,0,1)	00152800
DZW=ZL(I ,J,K,0,1)	00152900
DZN=ZL(I,JP1,K,0,2)	00153000
DZS=ZL(I,J ,K,0,2)	00153100
C *** CENTRAL LENGTH OF THE STAGGERED CONTROL VOLUME FOR T	00153200
DXEE=XL(IP2,J,K,0,1)	00153300
DXE =XL(IP1,J,K,0,1)	00153400
DXW =XL(I ,J,K,0,1)	00153500
DXWW=XL(IM1,J,K,0,1)	00153600
DYNN=YL(I,JP2,K,0,2)	00153700
DYN =YL(I,JP1,K,0,2)	00153800
DYS =YL(I,J ,K,0,2)	00153900
DYSS=YL(I,JM1,K,0,2)	00154000
DZFF=ZL(I,J,KP2,0,3)	00154100
DZF =ZL(I,J,KP1,0,3)	00154200
DZB =ZL(I,J,K ,0,3)	00154300
DZBB=ZL(I,J,KM1,0,3)	00154400
C *** DEFINE THE AREA OF THE CONTROL VOLUME	00154500
DXYF=DXF*DYF	00154600
DXYB=DXB*DYB	00154700
DYZE=DYE*DZE	00154800
	00154900
	00155000
	00155100
	00155200
	00155300
	00155400
	00155500
	00155600
	00155700
	00155800
	00155900
	00156000
	00156100
	00156200

DYZW=DYW*DZW	00156300
DZXN=DZN*DXN	00156400
DZXS=DZS*DXS	00156500
	00156600
VOL=DXI*DYJ*DZK	00156700
VOLDT=VOL/DTIME	00156800
	00156900
ZXOYN=DZXN/DYN	00157000
ZXOYS=DZXS/DYS	00157100
XYOZF=DXZF/DZF	00157200
XYOZB=DXZB/DZB	00157300
YZOXE=DYZE/DXE	00157400
YZOXW=DYZW/DXW	00157500
	00157600
GN=(R(I,J,K)*DYP1+R(I,JP1,K)*DYJ)/(DYP1+DYJ)	00157700
GS=(R(I,J,K)*DYM1+R(I,JM1,K)*DYJ)/(DYM1+DYJ)	00157800
GE=(R(I,J,K)*DXP1+R(IP1,J,K)*DXI)/(DXP1+DXI)	00157900
GW=(R(I,J,K)*DXM1+R(IM1,J,K)*DXI)/(DXM1+DXI)	00158000
GF=(R(I,J,K)*DZP1+R(I,J,KP1)*DZK)/(DZP1+DZK)	00158100
GB=(R(I,J,K)*DZM1+R(I,J,KM1)*DZK)/(DZM1+DZK)	00158200
	00158300
CN=GN*V(I,JP1,K)*DZXN	00158400
CS=GS*V(I,J,K)*DZXS	00158500
CE=GE*U(IP1,J,K)*DYZE	00158600
CW=GW*U(I,J,K)*DYZW	00158700
CF=GF*W(I,J,KP1)*DXYF	00158800
CB=GB*W(I,J,K)*DXYB	00158900
	00159000
	00159100
CONDN=1./((1./COND(I,J,K)*DYJ+1./COND(I,JP1,K)*DYP1)/(DYP1+DYJ))	00159200
CONDS=1./((1./COND(I,J,K)*DYJ+1./COND(I,JM1,K)*DYM1)/(DYM1+DYJ))	00159300
CONDE=1./((1./COND(I,J,K)*DXI+1./COND(IP1,J,K)*DXP1)/(DXP1+DXI))	00159400
CONDW=1./((1./COND(I,J,K)*DXI+1./COND(IM1,J,K)*DXM1)/(DXM1+DXI))	00159500
CONDF=1./((1./COND(I,J,K)*DZK+1./COND(I,J,KP1)*DZP1)/(DZP1+DZK))	00159600
CONDB=1./((1./COND(I,J,K)*DZK+1./COND(I,J,KM1)*DZM1)/(DZM1+DZK))	00159700
	00159800
CONDN1=ZXOYN*CONDN*ALEW	00159900
CONDS1=ZXOYS*CONDS*ALEW	00160000
CONDE1=YZOXE*CONDE*ALEW	00160100
CONDW1=YZOXW*CONDW*ALEW	00160200
CONDF1=XYOZF*CONDF*ALEW	00160300
CONDB1=XYOZB*CONDB*ALEW	00160400
	00162700
	00162800
CEP=(ABS(CE)+CE)*DXP1*DXI/(DXE*(DXE+DXW))/8.	00162801
CEM=(ABS(CE)-CE)*DXP1*DXI/(DXE*(DXE+DXEE))/8.	00162802
CWP=(ABS(CW)+CW)*DXM1*DXI/(DXW*(DXW+DXWW))/8.	00162803
CWM=(ABS(CW)-CW)*DXM1*DXI/(DXW*(DXW+DXE))/8.	00162804
	00162805
CNP=(ABS(CN)+CN)*DYP1*DYJ/(DYN*(DYN+DYS))/8.	00162806
CNM=(ABS(CN)-CN)*DYP1*DYJ/(DYN*(DYN+DYNM))/8.	00162807
CSP=(ABS(CS)+CS)*DYM1*DYJ/(DYS*(DYS+DYSS))/8.	00162808
CSM=(ABS(CS)-CS)*DYM1*DYJ/(DYS*(DYS+DYN))/8.	00162809
	00162810
CFP=(ABS(CF)+CF)*DZP1*DZK/(DZF*(DZF+DZB))/8.	00162811
CFM=(ABS(CF)-CF)*DZP1*DZK/(DZF*(DZF+DZFF))/8.	00162812
CBP=(ABS(CB)+CB)*DZM1*DZK/(DZB*(DZB+DZBB))/8.	00162813
CBM=(ABS(CB)-CB)*DZM1*DZK/(DZB*(DZB+DZF))/8.	00162814
	00162815
AE(I,J,K)=-.5*DXI/DXE*CE+CEP+CEM*(1.-DXE/DXEE)-CWM*DXW/DXE	00162816
AW(I,J,K)=-.5*DXI/DXW*CW+CWM+CWP*(1.-DXW/DXWW)+CFP*DXE/DXW	00162817
AN(I,J,K)=-.5*DYJ/DYN*CN+CNP+CNM*(1.-DYN/DYNN)+CSM*DYS/DYN	00162818
AS(I,J,K)=-.5*DYJ/DYS*CS+CSM+CSP*(1.-DYS/DYSS)+CNP*DYN/DYS	00162819
AF(I,J,K)=-.5*DZK/DZF*CF+CFP+CFM*(1.-DZF/DZFF)-CBM*DZB/DZF	00162820
AB(I,J,K)=-.5*DZK/DZB*CB+CBM+CBP*(1.-DZB/DZBB)+CFP*DZF/DZB	00162821
	00162822
	00162823
801 AEE=-CEM*DXE/DXEE	00162830

AEER=AEZ*CPD(IP2,J,K)	00162900
802 CONTINUE	00163000
	00163100
803 AWW=-CWP*DXW/DXWW	00163200
AWWR=AWW*CPD(IM2,J,K)	00163300
804 CONTINUE	00163400
	00163500
IF (J.LT.NJ) GOTO 805	00163600
ANN=0.	00163700
ANNR=0.	00163800
GOTO 806	00163900
805 ANN=-CNM*DYN/DYNN	00164000
ANNR=ANN*CPD(I,JP2,K)	00164100
806 CONTINUE	00164200
	00164300
IF (J.GT.2) GOTO 807	00164400
ASS=0.	00164500
ASSR=0.	00164600
GOTO 808	00164700
807 ASS=-CSP*DYS/DYSS	00164800
ASSR=ASS*CPD(I,JP2,K)	00164900
808 CONTINUE	00165000
	00165100
IF (K.LT.NK) GOTO 809	00165200
AFF=0.	00165300
AFFR=0.	00165400
GOTO 810	00165500
809 AFF=-CFM*DZF/DZFF	00165600
AFFR=AFF*CPD(I,J,KP2)	00165700
810 CONTINUE	00165800
	00165900
IF (K.GT.2) GOTO 811	00166000
ABB=0.	00166100
ABBR=0.	00166200
GOTO 812	00166300
811 ABB=-CBP*DZB/DZBB	00166400
ABBR=ABB*CPD(I,J,KM2)	00166500
812 CONTINUE	00166600
	00166700
	00166800
	00166900
C #####	00167000
C #####	00167100
C *** MODIFICATION FOR DECK BOUNDARIES	00167200
	00167300
900 CONTINUE	00167400
IF (NOD(IM1,J,K).EQ.0) GOTO 901	00167500
AWW=0.0	00167600
AWWR=0.0	00167700
	00167800
901 CONTINUE	00167900
IF (NOD(IP1,J,K).EQ.0) GOTO 902	00168000
AEZ=0.0	00168100
AEER=0.0	00168200
	00168300
902 CONTINUE	00168400
IF (NOD(I,CM1,K).EQ.0) GOTO 903	00168500
ASS=0.0	00168600
ASSR=0.0	00168700
	00168800
903 CONTINUE	00168900
IF (NOD(I,JP1,K).EQ.0) GOTO 904	00169000
ANN=0.0	00169100
ANNR=0.0	00169200
	00169300
904 CONTINUE	00169400
IF (NOD(I,J,KM1).EQ.0) GOTO 905	00169500
ABB=0.0	00169600

ABBR=0.0	00169700
905 CONTINUE	00169800
IF (NOD(I,J,KP1).EQ.0) GOTO 906	00169900
AFF=0.0	00170000
AFFR=0.0	00170100
906 CONTINUE	00170200
C *****	00170300
C *****	00170400
AP(I,J,K)=(AE(I,J,K)+AW(I,J,K)+AN(I,J,K)+AS(I,J,K)	00170500
6 +AF(I,J,K)+AB(I,J,K)+AEE+AWW+ANN+ASS+AFF+ABB)	00170600
6 +CONDE1+CONDW1+CONDN1+CONDS1+CONDF1+CONDB1	00170700
	00170800
AE(I,J,K)=AE(I,J,K)+CONDE1	00170900
AW(I,J,K)=AW(I,J,K)+CONDW1	00171000
AN(I,J,K)=AN(I,J,K)+CONDN1	00171100
AS(I,J,K)=AS(I,J,K)+CONDS1	00171200
AF(I,J,K)=AF(I,J,K)+CONDF1	00171300
AB(I,J,K)=AB(I,J,K)+CONDB1	00171400
	00171500
SP(I,J,K)=-ROD(I,J,K)*VOLDT	00171600
SU(I,J,K)=ROD(I,J,K)*VOLDT*TOD(I,J,K)	00171700
SU(I,J,K)=SU(I,J,K)+AEER+AWWR+ANNR+ASSR+AFFR+ABBR	00171800
100 CONTINUE	00171900
C *** TAKE CARE OF B.C. THRU AN,AS,AE,AW,AF,AB,SP AND SU	00172000
C	00172100
C *** RADIUS DIRECTION	00172200
	00172300
DO 500 I=2,NI	00172400
DO 500 K=2,NK	00172500
CC SP(I,2,K)=SP(I,2,K)+AS(I,2,K)	00172600
SP(I,2,K)=SP(I,2,K)-AS(I,2,K)	00172700
SU(I,2,K)=SU(I,2,K)+2.0*AS(I,2,K)*CPD(I,1,K)	00172800
SP(I,NJ,K)=SP(I,NJ,K)-AN(I,NJ,K)	00172900
SU(I,NJ,K)=SU(I,NJ,K)+2.*CPD(I,NJF1,K)*AN(I,NJ,K)	00173000
AS(I,2,K)=0.	00173100
AN(I,NJ,K)=0.	00173200
500 CONTINUE	00173300
C *** CYLIC CONDITIONS	00173400
	00173500
DO 600 J=2,NJ	00173600
DO 600 K=2,NK	00173700
SU(2,J,K)=SU(2,J,K)+AW(2,J,K)*C(1,J,K)	00173800
SU(NI,J,K)=SU(NI,J,K)+AE(NI,J,K)*C(NIP1,J,K)	00173900
AW(2,J,K)=0.0	00174000
AE(NI,J,K)=0.0	00174100
600 CONTINUE	00174200
C *** END OF SPHERE	00174300
	00174400
DO 700 I=2,NI	00174500
DO 700 J=2,NJ	00174600
SP(I,J,2)=SP(I,J,2)+AB(I,J,2)	00174700
SP(I,J,NK)=SP(I,J,NK)+AF(I,J,NK)	00174800
AB(I,J,2)=0.	00174900
AF(I,J,NK)=0.	00175000
700 CONTINUE	00175100
	00175200
C *** ASSEMBLE COEFFICIENTS AND SOLVE DIFFERENCE EQUATIONS	00175300
	00175400
DO 300 K=2,NK	00175500
	00175600
	00175700
	00175800
	00175900
	00176000
	00176100
	00176200
	00176300
	00176400


```

DO 300 J=2,NJ
DO 300 I=2,NI
AP(I,J,K)=AP(I,J,K)-SP(I,J,K)
300 CONTINUE

```

C *** VOLUME MASS SOURCE INPUT

```

VOLT=0.0
DO 113 I=2,NI
DO 113 J=2,NJ
DO 113 K=16,17
IF (NHSZ(I,J,K).EQ.0) GOTO 113
DXI =XL(I,J,K,0,0)
DYJ =YL(I,J,K,0,0)
DZK =ZL(I,J,K,0,0)
VOL=DXI*DYJ*DZK*H*H*H
VOLT=VOLT+VOL
113 CONTINUE

```

```

DO 111 I=2,NI
DO 111 J=2,NJ
DO 111 K=16,17
IF (NHSZ(I,J,K).EQ.0) GOTO 111
DXI =XL(I,J,K,0,0)
DYJ =YL(I,J,K,0,0)
DZK =ZL(I,J,K,0,0)
QQQ=Q*H/(UO*CPO*RHO0*TA)
QMS= 1.0
QMS = QMS*H/(UO*RHO0)
VOL=DXI*DYJ*DZK
SU(I,J,K)=SU(I,J,K)+VOL*QMS/VOLT
111 CONTINUE

```

C *** SOLVE FOR C

```
CALL TRID (2,2,2,NI,NJ,1,NK,C)
```

C **** RESET CONCENTRATION AT R=0.0 AND END OF SPHERE

```

DO 81 K=1,NKP1
AVT=0.0
DO 82 I=2,NI
AVT=AVT+(C(I,2,K)/NIM1)
82 CONTINUE
DO 83 I=1,NIP1
C(I,1,K)=AVT
83 CONTINUE
81 CONTINUE

```

```

DO 74 I=1,NIP1
DO 74 J=1,NJP1
C(I,J,1)=C(I,J,2)
C(I,J,NKP1)=C(I,J,NK)
74 CONTINUE

```

C *** FOR SURFACE MASS EXCHANGE WITH SURROUNDING

```

DO 84 I=2,NI
DO 84 K=2,NK
C(I,NJP1,K)=C(I,NJ,K)
84 CONTINUE

```

C *** FOR CYLIC CONDITION

```
DO 80 J=1,NJP1
```

```

00176500
00176600
00176700
00176800
00176900
00177000
00177100
00177200
00177300
00177400
00177500
00177600
00177700
00177800
00177900
00178000
00178100
00178200
00178300
00178400
00178500
00178600
00178700
00178800
00178900
00179000
00179100
00179200
00179300
00179400
00179500
00179600
00179700
00179800
00179900
00180000
00180100
00180200
00180300
00180400
00180500
00180600
00180700
00180800
00180900
00181000
00181100
00181200
00181300
00181400
00181500
00181600
00181700
00181800
00181900
00182000
00182100
00182200
00182300
00182400
00182500
00182600
00182700
00182800
00182900
00183000
00183100
00183200

```

DO 80 K=1,NKP1	00183300
C(1,J,K)=C(NI,J,K)	00183400
C(NIP1,J,K)=C(2,J,K)	00183500
80 CONTINUE	00183600
	00183700
RETURN	00183800
END	00183900
	00184000
	00184100
	00184200
C *****	00184300
C SUBROUTINE CALU	00184400
C *****	00184500
COMMON/R4/XC(93),YC(93),ZC(93),XS(93),YS(93),ZS(93),	00184600
& DXXC(93),DYXC(93),DZZC(93),DXXS(93),DYYS(93),DZZS(93)	00184700
COMMON/BL1/DX,DY,DZ,VOL,DTIME,VOLDT,THOT,TCOOL,PI,Q,QR	00184800
COMMON/BL7/NI,NIP1,NIM1,NJ,NJP1,NJM1,NK,NKP1,NKM1	00184900
& ,NIP2,NJP2,NKP2,NA,NAP1,NAM1,NB,NBP1,NBM1,KRUN,NCHIP,NJRA,NWRP	00185000
COMMON/BL12/ NWRITE,NTAPE,NTMAXO,NTREAL,TIME,SORSUM,ITER	00185100
COMMON/BL14/HCOEF,TINF,CNT,ABTURB,BTURB,VISL,VISMAX,QCORRT,PM1,PM2	00185200
COMMON/BL16/ CONST1,CONST2,CONST3,CONST4,CONST6,NT,UO,H,UGRT,BUOY,	00185300
& CPO,PRT,CONDO,VISO,RHOO,HR,TR,TA,DTEMP,TWRITE,TTAPE,TMAX,GC,RAIRO	00185400
COMMON/BL20/SIG11(22,16,32),SIG12(22,16,32),SIG22(22,16,32)	00185500
& ,SIG13(22,16,32),SIG23(22,16,32),SIG33(22,16,32)	00185600
COMMON/BL22/ICHPB(10),NCHPI(10),JCHPB(10),NCHPJ(10),KCHPB(10),	00185700
& NCHPK(10),TCHP(10),CPS(10),CONS(10),WFAN(10)	00185800
COMMON/BL31/ TOD(22,16,32),ROD(22,16,32),POD(22,16,32)	00185900
& ,COD(22,16,32),UOD(22,16,32),VOD(22,16,32),WOD(22,16,32)	00186000
COMMON/BL32/ T(22,16,32),R(22,16,32),P(22,16,32)	00186100
& ,C(22,16,32),U(22,16,32),V(22,16,32),W(22,16,32)	00186200
COMMON/BL33/ TPD(22,16,32),RPD(22,16,32),PPD(22,16,32)	00186300
& ,CPD(22,16,32),UPD(22,16,32),VPD(22,16,32),WPD(22,16,32)	00186400
COMMON/BL34/ HEIGHT(22,16,32),REQ(22,16,32),	00186500
& SMP(22,16,32),SMPP(22,16,32),PP(22,16,32),	00186600
& DU(22,16,32),DV(22,16,32),DW(22,16,32)	00186700
COMMON/BL36/AP(22,16,32),AE(22,16,32),AW(22,16,32),AN(22,16,32),	00186800
& AS(22,16,32),AF(22,16,32),AB(22,16,32),	00186900
& SP(22,16,32),SV(22,16,32),RI(22,16,32)	00187000
COMMON/BL37/ VIS(22,16,32),COND(22,16,32),NOD(22,16,32),RWALL(579)	00187100
& ,CPM(22,16,32),HSZ(3,2),NHSZ(22,16,32),RESORM(93)	00187200
	00187300
C *** CALCULATE COEFFICIENTS	00187400
	00187500
DO 100 K=2,NK	00187600
KP2=K+2	00187700
KP1=K-1	00187800
KM1=K-1	00187900
KM2=K-2	00188000
DO 100 J=2,NJ	00188100
JP2=J+2	00188200
JP1=J+1	00188300
JM1=J-1	00188400
JM2=J-2	00188500
DO 100 I=2,NI	00188600
IP2=I+2	00188700
IP1=I+1	00188800
IM1=I-1	00188900
IM2=I-2	00189000
IF (I.EQ.2) IM1=NI	00189100
IF (I.EQ.2) IM2=NIM1	00189200
IF (I.EQ.3) IM2=NI	00189300
IF (I.EQ.NI) IP2=3	00189400
	00189500
	00189600
C CENTRAL LENGTH OF THE SCALE CONTROL VOLUME	00189700
	00189800
DXP1=XL(IP1,K,1,0)	00189900
DXI=XL(I,J,K,1,0)	00190000

DXM1=XL(IM1,J,K,1,0)	00190100
DYP1=YL(I,JP1,K,1,0)	00190200
DYJ =YL(I,J ,K,1,0)	00190300
DYM1=YL(I,JM1,K,1,0)	00190400
	00190500
DZP1=ZL(I,J,KP1,1,0)	00190600
DZK =ZL(I,J,K ,1,0)	00190700
DZM1=ZL(I,J,KM1,1,0)	00190800
	00190900
C *** SURFACE LENGTH OF THE CONTROL VOLUME	00191000
	00191100
	00191200
DXN=XL(I,JP1,K,1,2)	00191300
DXS=XL(I,J ,K,1,2)	00191400
DXF=XL(I,J,KP1,1,3)	00191500
DXB=XL(I,J,K ,1,3)	00191600
	00191700
DYF=YL(I,J,KP1,1,3)	00191800
DYB=YL(I,J,K ,1,3)	00191900
DYE=YL(IP1,J,K,1,1)	00192000
DYW=YL(I ,J,K,1,1)	00192100
	00192200
DZE=ZL(IP1,J,K,1,1)	00192300
DZW=ZL(I ,J,K,1,1)	00192400
DZN=ZL(I,JP1,K,1,2)	00192500
DZS=ZL(I,J ,K,1,2)	00192600
	00192700
C *** CENTRAL LENGTH OF THE STAGGERED CONTROL VOLUME FOR U	00192800
	00192900
DXEE=XL(IP2,J,K,1,1)	00193000
DXE =XL(IP1,J,K,1,1)	00193100
DXW =XL(I ,J,K,1,1)	00193200
DXWW=XL(IM1,J,K,1,1)	00193300
	00193400
DYNN=YL(I,JP2,K,1,2)	00193500
DYN =YL(I,JP1,K,1,2)	00193600
DYS =YL(I,J ,K,1,2)	00193700
DYSS=YL(I,JM1,K,1,2)	00193800
	00193900
DZFF=ZL(I,J,KP2,1,3)	00194000
DZF =ZL(I,J,KP1,1,3)	00194100
DZB =ZL(I,J,K ,1,3)	00194200
DZBB=ZL(I,J,KM1,1,3)	00194300
	00194400
C *** DEFINE THE AREA OF THE CONTROL VOLUME	00194500
	00194600
DXYF=DXF*DYF	00194700
DXYB=DXB*DYB	00194800
DYZE=DYE*DZE	00194900
DYZW=DYW*DZW	00195000
DZXN=DZN*DXN	00195100
DZXS=DZS*DXS	00195200
	00195300
VOL=DXI*DYJ*DZK	00195400
VOLDT=VOL/DTIME	00195500
	00195600
ZXOYN=DZXN/DYN	00195700
ZXOYS=DZXS/DYS	00195800
XYOZF=DXYF/DZF	00195900
XYOZB=DXYB/DZB	00196000
YZOKE=DYZE/DXE	00196100
YZOXW=DYZW/DXW	00196200
	00196300
	00196400
C *** USE SINGLE AND BI-LINEAR INTERPOLATION TO EVALUATE	00196500
C PHYSICAL PROPERTIES AND FLUX ON THE SURFACES.	00196600
	00196700
	00196800

GNE=SILIN(R(I ,JP1,K),R(I ,J,K),DYP1,DYJ)*V(I ,JP1,K)	00196900
GNW=SILIN(R(IM1,JP1,K),R(IM1,J,K),DYP1,DYJ)*V(IM1,JP1,K)	00197000
GSE=SILIN(R(I ,JM1,K),R(I ,J,K),DYM1,DYJ)*V(I ,J ,K)	00197100
GSW=SILIN(R(IM1,JM1,K),R(IM1,J,K),DYM1,DYJ)*V(IM1,J ,K)	00197200
	00197300
GE =SILIN(R(IP1,J,K),R(I ,J,K),DXEE,DXE)*U(IP1,J,K)	00197400
GP =SILIN(R(IM1,J,K),R(I ,J,K),DXW ,DXE)*U(I ,J,K)	00197500
GW =SILIN(R(IM2,J,K),R(IM1,J,K),DXWW,DXW)*U(IM1,J,K)	00197600
	00197700
GFE=SILIN(R(I ,J,KP1),R(I ,J,K),DZP1,DZK)*W(I ,J,KP1)	00197800
GFW=SILIN(R(IM1,J,KP1),R(IM1,J,K),DZP1,DZK)*W(IM1,J,KP1)	00197900
GBE=SILIN(R(I ,J,KM1),R(I ,J,K),DZM1,DZK)*W(I ,J,K)	00198000
GBW=SILIN(R(IM1,J,KM1),R(IM1,J,K),DZM1,DZK)*W(IM1,J,K)	00198100
	00198200
CE=0.5*(GE+GP)*DYZE	00198300
CW=0.5*(GP+GW)*DYZW	00198400
	00198500
CN=SILIN(GNE,GNW,DXE,DXW)*DZXN	00198600
CS=SILIN(GSE,GSW,DXE,DXW)*DZXS	00198700
	00198800
CF=SILIN(GFE,GFW,DXE,DXW)*DXYF	00198900
CB=SILIN(GBE,GBW,DXE,DXW)*DXYB	00199000
	00199100
WISE=VIS(I ,J,K)	00199200
VISW=VIS(IM1,J,K)	00199300
	00199400
VISN= (VIS(I ,JP1,K)+VIS(I ,J,K)+	00199500
4 VIS(IM1,JP1,K)+VIS(IM1,J,K))/4.0	00199600
VISS= (VIS(I ,JM1,K)+VIS(I ,J,K)+	00199700
4 VIS(IM1,JM1,K)+VIS(IM1,J,K))/4.0	00199800
	00199900
VISF= (VIS(I ,J,KP1)+VIS(I ,J,K)+	00200000
4 VIS(IM1,J,KP1)+VIS(IM1,J,K))/4.0	00200100
VISB= (VIS(I ,J,KM1)+VIS(I ,J,K)+	00200200
4 VIS(IM1,J,KM1)+VIS(IM1,J,K))/4.0	00200300
	00200400
	00200500
VISN1=ZXOYN*VISN	00200600
VISS1=ZXOYS*VISS	00200700
WISE1=YZOXE*WISE	00200800
VISW1=YZOXW*VISW	00200900
VISF1=XYOZF*VISF	00201000
VISB1=XYOZB*VISB	00201100
	00201200
	00201300
CEP=(ABS(CE)-CE)*DXE/DXE/16.	00201400
CEM=(ABS(CE)-CE)*DXE/DXP1/16.	00201500
CWP=(ABS(CW)+CW)*DXW/DXM1/16.	00201600
CWM=(ABS(CW)-CW)*DXW/DXE/16.	00201700
	00201800
CNP=(ABS(CN)+CN)*DYP1*DYJ/(DYN*(DYN+DYS))/8.	00201900
CNM=(ABS(CN)-CN)*DYP1*DYJ/(DYN*(DYN+DYN))/8.	00202000
CSP=(ABS(CS)+CS)*DYM1*DYJ/(DYS*(DYS+DYSS))/8.	00202100
CSM=(ABS(CS)-CS)*DYM1*DYJ/(DYS*(DYS+DYN))/8.	00202200
	00202300
CFP=(ABS(CF)+CF)*DZP1*DZK/(DZF*(DZF+DZB))/8.	00202400
CFM=(ABS(CF)-CF)*DZP1*DZK/(DZF*(DZF+DZFF))/8.	00202500
CBP=(ABS(CB)+CB)*DZM1*DZK/(DZB*(DZB+DZBB))/8.	00202600
CBM=(ABS(CB)-CB)*DZM1*DZK/(DZB*(DZB+DZF))/8.	00202700
	00202800
AE(I,J,K)=-.5*CE+CEP-CEM*(1.-DXE/DXEE)+CWM*DXW/DXE-VISE1	00202900
AW(I,J,K)=.5*CW+CWM-CWP*(1.-DXW/DXWW)+CEP*DXE/DXW+VISW1	00203000
	00203100
	00203200
AN(I,J,K)=-.5*DYJ/DYN*CN+CNP-CNM*(1.-DYN/DYNN)+CSM*DYS/DYN+VISN1	00203300
AS(I,J,K)=.5*DYJ/DYS*CS+CSM-CSP*(1.-DYS/DYSS)+CNP*DYN/DYS+VISS1	00203310
AF(I,J,K)=-.5*DZK/DZF*CF+CFP-CFM*(1.-DZF/DZFF)+CBM*DZB/DZF+VISF1	00203320
AB(I,J,K)=.5*DZK/DZB*CB+CBM-CBP*(1.-DZB/DZBB)+CFP*DZF/DZB+VISB1	00203330

801	AEZ=-CEX*DXE/DXEE	00203340
	AEER=AEZ*UPD(IP2,J,K)	00203350
802	CONTINUE	00203360
		00203370
		00203380
803	AWW=-CXZ*DXW/DXWW	00203390
	AWWR=AWW*UPD(IM2,J,K)	00204000
804	CONTINUE	00204100
		00204200
	IF (J.LT.NJ) GOTO 805	00204300
	ANN=0.	00204400
	ANNR=0.	00204500
	GOTO 806	00204600
805	ANN=-CNM*DYN/DYNN	00204700
	ANNR=ANN*UPD(I,JP2,K)	00204800
806	CONTINUE	00204900
		00205000
	IF (J.GT.2) GOTO 807	00205100
	ASS=0.	00205200
	ASSR=0.	00205300
	GOTO 808	00205400
807	ASS=-CSZ*DYS/DYSS	00205500
	ASSR=ASS*UPD(I,JM2,K)	00205600
808	CONTINUE	00205700
		00205800
	IF (K.LT.NK) GOTO 809	00205900
	AFF=0.	00206000
	AFFR=0.	00206100
	GOTO 810	00206200
809	AFF=-CFX*DZF/DZFF	00206300
	AFFR=AFF*UPD(I,J,KP2)	00206400
810	CONTINUE	00206500
		00206600
	IF (K.GT.2) GOTO 811	00206700
	ABB=0.	00206800
	ABBR=0.	00206900
	GOTO 812	00207000
811	ABB=-CFZ*DZB/DZBB	00207100
	ABBR=ABB*UPD(I,J,KM2)	00207200
812	CONTINUE	00207300
		00207400
		00207500
C	*****	00207600
C	*****	00207700
C	*** MODIFICATION FOR DECK BOUNDARIES	00207800
		00207900
900	CONTINUE	00208000
	IF (NOD(IM2,J,K).EQ.0) GOTO 901	00208100
	AWW=0.0	00208200
	AWWR=0.0	00208300
		00208400
901	CONTINUE	00208500
	IF (NOD(JP1,J,K).EQ.0) GOTO 902	00208600
	AEZ=0.0	00208700
	AEER=0.0	00208800
		00208900
902	CONTINUE	00209000
	IF (NOD(I,JM1,K).EQ.0) GOTO 903	00209100
	ASS=0.0	00209200
	ASSR=0.0	00209300
		00209400
903	CONTINUE	00209500
	IF (NOD(I,JP1,K).EQ.0) GOTO 904	00209600
	ANN=0.0	00209700
	ANNR=0.0	00209800
904	CONTINUE	00209900
	IF (NOD(I,J,KM1).EQ.0) GOTO 905	00210000

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ABB=0.0
ABBR=0.0

905 CONTINUE
IF (NOD(I,J,KP1).EQ.0) GOTO 906
AFF=G.0
AFFR=0.0

906 CONTINUE
C #####
C #####

C *** SU FROM NORMAL STRESS

RE=(SIG11(I,J,K)-(U(IP1,J,K)-U(I,J,K))*VISE/DXE)*DYZE
RW=(SIG11(IM1,J,K)-(U(I,J,K)-U(IM1,J,K))*VISW/DXW)*DYZW
RN=(SIG12(I,JP1,K)-(U(I,JP1,K)-U(I,J,K))*VISN/DYN)*DZXN
RS=(SIG12(I,J,K)-(U(I,J,K)-U(I,IM1,K))*VISS/DYS)*DZXS
RF=(SIG13(I,J,KP1)-(U(I,J,KP1)-U(I,J,K))*VISF/DZF)*DXYF
RB=(SIG13(I,J,K)-(U(I,J,K)-U(I,J,KM1))*VISB/DZB)*DXYB

C *** SU FROM CURVED STRESSES AND ACCELERATIONS

AVG12=0.5*(SIG12(I,JP1,K)+SIG12(I,J,K))
AVG13=0.5*(SIG13(I,J,KP1)+SIG13(I,J,K))
AVG22=SILIN(SIG22(I,J,K),SIG22(IM1,J,K),DXE,DXW)
AVG33=SILIN(SIG33(I,J,K),SIG33(IM1,J,K),DXE,DXW)

AU1=U(I,J,K)
AU2=BILIN(V(I,JP1,K),V(I,J,K),DYJ,DYJ,
        V(IM1,JP1,K),V(IM1,J,K),DYJ,DYJ,DXE,DXW)
AU3=BILIN(W(I,J,KP1),W(I,J,K),DZK,DZK,
        W(IM1,J,KP1),W(IM1,J,K),DZK,DZK,DXE,DXW)

AR=SILIN(R(I,J,K),R(IM1,J,K),DXE,DXW)

ARU12=AR*AU1*AU2
ARU13=AR*AU1*AU3
ARU22=AR*AU2*AU2
ARU33=AR*AU3*AU3

RRY=(AVG12-ARU12)*DZK*(DXN-DXS)
RRZ=(AVG13-ARU13)*DYJ*(DXF-DXB)
RRX=(AVG22-ARU22)*DZK*(DYE-DYW)+
        (AVG33-ARU33)*DYJ*(DZE-DZW)

AP(I,J,K)=AE(I,J,K)+AW(I,J,K)+AN(I,J,K)+AS(I,J,K)
        -AF(I,J,K)+AB(I,J,K)+AEE+AWN+ANN+ASS+AFF+ABB
SP(I,J,K)=-(ROD(I,J,K)*DXW+ROD(IM1,J,K)*DXE)/(DXW+DXE)*VOLDT
SU(I,J,K)=(ROD(I,J,K)*DXW+ROD(IM1,J,K)*DXE)/(DXW+DXE)*VOLDT
        +UOD(I,J,K)
SU(I,J,K)=SU(I,J,K)+DYJ*DZK*(P(IM1,J,K)-P(I,J,K))
        -AEER+AWWR+ANNR+ASSR+AFFR+ABBR
        -RE-RW-RN-RS-RF-RB+RRY+RRZ-RRX
        -BUOY*SIN(ZC(K))*((R(I,J,K)-REQ(I,J,K))*DXW+COS(XC(I))-(R(IM1,
        J,K)-REQ(IM1,J,K))*DXE+COS(XC(IM1)))/(DXW+DXE)*VOL

100 CONTINUE

C *** TAKE CARE OF S.C. THRU AN,AS,AE,AW,AF,AB,SP AND SU
C
C *** RADIUS DIRECTION

DO 500 K=2,NK
DO 500 I=2,N1
CC JP(I,2,K)=SP(I,2,K)-AS(I,2,K)

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00210100
00210200
00210300
00210400
00210500
00210600
00210700
00210800
00210900
00211000
00211100
00211200
00211300
00211400
00211500
00211600
00211700
00211800
00211900
00212000
00212100
00212200
00212300
00212400
00212500
00212600
00212700
00212800
00212900
00213000
00213100
00213200
00213300
00213400
00213500
00213600
00213700
00213800
00213900
00214000
00214100
00214200
00214300
00214400
00214500
00214600
00214700
00214800
00214900
00215000
00215100
00215200
00215300
00215400
00215500
00215600
00215700
00215800
00215900
00216000
00216100
00216200
00216300
00216400
00216500
00216600
00216700
00216800

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SP(I,2,K)=SP(I,2,K)-AS(I,2,K)	00216900
SU(I,2,K)=SU(I,2,K)-2.0*U(I,1,K)*AS(I,2,K)	00217000
SP(I,NJ,K)=SP(I,NJ,K)-AN(I,NJ,K)	00217100
AN(I,NJ,K)=0.	00217200
AS(I,2,K)=0.	00217300
500 CONTINUE	00217400
	00217500
C *** CYLIC CONDITION	00217600
	00217700
DO 502 K=2,NK	00217800
DO 502 J=2,NJ	00217900
SU(2,J,K)=SU(2,J,K)+AW(2,J,K)*U(1,J,K)	00218000
SU(NI,J,K)=SU(NI,J,K)+AE(NI,J,K)*U(NIP1,J,K)	00218100
AW(2,J,K)=0.0	00218200
AE(NI,J,K)=0.0	00218300
502 CONTINUE	00218400
	00218500
C *** FRONT AND BACK WALLS	00218600
	00218700
DO 600 I=2,N1	00218800
DO 600 J=2,NJ	00218900
	00219000
C *** SLIP WALLS	00219100
SP(I,J,2)=SP(I,J,2)+AB(I,J,2)	00219200
SP(I,J,NK)=SP(I,J,NK)+AF(I,J,NK)	00219300
	00219400
AF(I,J,NK)=0.	00219500
AB(I,J,2)=0.	00219600
600 CONTINUE	00219700
	00219800
	00219900
	00220000
	00220100
IF (NCHIP.EQ.0) GOTO 105	00220200
C *****	00220300
C *****	00220400
C *** MODIFICATION FOR DECK BOUNDARIES	00220500
	00220600
DO 101 N=1,NCHIP	00220700
IB=ICHPB(N)	00220800
IE=IB-NCHPI(N)-1	00220900
IBM1=IB-1	00221000
IEP1=IE+1	00221100
JB=JCHPB(N)	00221200
JE=JB-NCHPJ(N)-1	00221300
JBM1=JB-1	00221400
JEP1=JE+1	00221500
KB=KCHPB(N)	00221600
KE=KB-NCHPK(N)-1	00221700
KBM1=KB-1	00221800
KEP1=KE+1	00221900
	00222000
DO 102 J=JB,JE-1	00222100
DO 102 K=KB,KE-1	00222200
AE(IBM1,J,K)=0.0	00222300
AW(IEP1,J,K)=0.0	00222400
	00222500
102 CONTINUE	00222600
	00222700
DO 103 I=IB,IE	00222800
DO 103 K=KB,KE-1	00222900
SP(I,JBM1,K)=SP(I,JBM1,K)-AN(I,JBM1,K)	00223000
AN(I,JBM1,K)=0.0	00223100
	00223200
SP(I,JE,K)=SP(I,JE,K)-AS(I,JE,K)	00223300
AS(I,JE,K)=0.0	00223400
103 CONTINUE	00223500
	00223600

DO 106 I=IB,IE	00223700
DO 106 J=JB,JE-1	00223800
SP(I,J,KBM1)=SP(I,J,KBM1)-AF(I,J,KBM1)	00223900
AF(I,J,KBM1)=0.0	00224000
	00224100
SP(I,J,KE)=SP(I,J,KE)-AB(I,J,KE)	00224200
AB(I,J,KE)=0.0	00224300
106 CONTINUE	00224400
	00224500
	00224600
C *** FOR THE CELLS INSIDE OF THE DECKS	00224700
	00224800
DO 104 I=IB,IE	00224900
DO 104 J=JB,JE-1	00225000
DO 104 K=KB,KE-1	00225100
SP(I,J,K)=-1.0E20	00225200
AW(I,J,K)=0.	00225300
AE(I,J,K)=0.	00225400
AS(I,J,K)=0.	00225500
AN(I,J,K)=0.	00225600
SU(I,J,K)=0.	00225700
104 CONTINUE	00225800
101 CONTINUE	00225900
105 CONTINUE	00226000
	00226100
C *****	00226200
C *****	00226300
	00226400
	00226500
	00226600
C *** ASSEMBLE COEFFICIENTS AND SOLVE DIFFERENCE EQUATIONS	00226700
	00226800
DO 301 K=2,NK	00226900
DO 301 J=2,NJ	00227000
DO 301 I=2,NI	00227100
DYJ=YL(I,J,K,1,0)	00227200
DZK=ZL(I,J,K,1,0)	00227300
DYZ=DYJ*DZK	00227400
AP(I,J,K)=AP(I,J,K)-SP(I,J,K)	00227500
DJ(I,J,K)=DYJ/AP(I,J,K)	00227600
301 CONTINUE	00227700
	00227800
	00227900
	00228000
C *** SOLVE FOR U	00228100
	00228200
CALL TRID (2,2,2,NI,NJ,NK,U)	00228300
	00228400
DO 74 I=2,NIP1	00228500
DO 74 J=2,NJP1	00228600
U(I,J,1)=U(I,J,2)	00228700
U(I,J,NKP1)=U(I,J,NK)	00228800
74 CONTINUE	00228900
	00229000
	00229100
DO 79 I=1,NIP1	00229200
DO 79 K=1,NKP1	00229300
C U(I,1,K)=U(I,2,K)	00229400
79 CONTINUE	00229500
	00229600
	00229700
	00229800
IF (NCHIP.EQ.0) GOTO 112	00229900
C *****	00230000
C *****	00230100
C *** RESET THE VELOCITY INSIDE OF DECK	00230200
	00230300
DO 110 N=1,NCHIP	00230400
IB=ICHFB(N)	

IE=IB+NCHPI(N)-1	00230500
JB=JCHPB(N)	00230600
JE=JB+NCHPJ(N)-1	00230700
KB=KCHPB(N)	00230800
KE=KB+NCHPK(N)-1	00230900
DO 108 I=IB,IE	00231000
DO 108 J=JB,JE-1	00231100
DO 108 K=KB,KE-1	00231200
U(I,J,K)=0.0	00231300
108 CONTINUE	00231400
110 CONTINUE	00231500
112 CONTINUE	00231600
C *****	00231700
C *****	00231800
RETURN	00231900
END	00232000
	00232100
	00232200
	00232300
	00232400
	00232500
C *****	00232600
C SUBROUTINE CALV	00232700
C *****	00232800
	00232900
COMMON/R4/XC(93),YC(93),ZC(93),XS(93),YS(93),ZS(93),	00233000
& DXXC(93),DYXC(93),DZZC(93),DXXS(93),DYYS(93),DZZS(93)	00233100
COMMON/BL1/DX,DY,DZ,VOL,DTIME,VOLDT,THOT,TCOOL,PI,Q,QR	00233200
COMMON/BL7/NI,NIP1,NIM1,NJ,NJP1,NJM1,NK,NKP1,NKM1	00233300
& ,NIP2,NJP2,NKP2,NA,NAP1,NAM1,NB,NBP1,NBM1,KRUN,NCHIP,NJRA,NWRP	00233400
COMMON/BL12/ NWRITE,NTAPE,NTMAX0,NTREAL,TIME,SORSUM,ITER	00233500
COMMON/BL16/ CONST1,CONST2,CONST3,CONST4,CONST6,NT,UO,H,UGRT,BUOY,	00233600
& CPO,PRT,CONDO,VISO,RHOO,HR,TR,TA,TEMP,TWRITE,TTAPE,TMAX,GC,RAIR	00233700
COMMON/BL20/SIG11(22,16,32),SIG12(22,16,32),SIG22(22,16,32)	00233800
& ,SIG13(22,16,32),SIG23(22,16,32),SIG33(22,16,32)	00233900
COMMON/BL22/ICHPB(10),NCHPI(10),JCHPB(10),NCHPJ(10),KCHPB(10),	00234000
& NCHPK(10),TCHP(10),CPS(10),CONS(10),WFAN(10)	00234100
COMMON/BL31/ TOD(22,16,32),ROD(22,16,32),POD(22,16,32)	00234200
& ,COD(22,16,32),UOD(22,16,32),VOD(22,16,32),WOD(22,16,32)	00234300
COMMON/BL32/ T(22,16,32),R(22,16,32),P(22,16,32)	00234400
& ,C(22,16,32),U(22,16,32),V(22,16,32),W(22,16,32)	00234500
COMMON/BL33/ TPD(22,16,32),RPD(22,16,32),PPD(22,16,32)	00234600
& ,CPD(22,16,32),UPD(22,16,32),VPD(22,16,32),WPD(22,16,32)	00234700
COMMON/BL34/ HEIGHT(22,16,32),REQ(22,16,32),	00234800
& SMP(22,16,32),SMPP(22,16,32),PP(22,16,32),	00234900
& DU(22,16,32),DV(22,16,32),DW(22,16,32)	00235000
COMMON/BL36/AP(22,16,32),AE(22,16,32),AW(22,16,32),AN(22,16,32),	00235100
& AS(22,16,32),AF(22,16,32),AB(22,16,32),	00235200
& SP(22,16,32),SU(22,16,32),RI(22,16,32)	00235300
COMMON/BL37/ VTS(22,16,32),COND(22,16,32),NOD(22,16,32),RWALL(579)	00235400
& ,CPM(22,16,32),HSZ(3,2),NHSZ(22,16,32),RESORM(93)	00235500
	00235600
	00235700
C *** CALCULATE COEFFICIENTS	00235800
	00235900
DO 100 K=2,NK	00236000
KP2=K+2	00236100
KP1=K-1	00236200
KM1=K-1	00236300
KM2=K-2	00236400
DO 100 J=3,NJ	00236500
JP2=J+2	00236600
JP1=J+1	00236700
JM1=J-1	00236800
JM2=J-2	00236900
DO 100 I=2,NI	00237000
IP2=I+2	00237100
IP1=I+1	00237200

IM1=-1	00237300
IM2=-2	00237400
IF (I.EQ.2) IM2=NIM1	00237500
IF (I.EQ.NI) IP2=3	00237600
	00237700
C CENTRAL LENGTH OF THE SCALE CONTROL VOLUME	00237800
	00237900
	00238000
DXP1=XL(IP1,J,K,2,0)	00238100
DXI =XL(I ,J,K,2,0)	00238200
DXM1=XL(IM1,J,K,2,0)	00238300
	00238400
DYP1=YL(I,JP1,K,2,0)	00238500
DYJ =YL(I,J ,K,2,0)	00238600
DYM1=YL(I,JM1,K,2,0)	00238700
	00238800
DZP1=ZL(I,J,KP1,2,0)	00238900
DZK =ZL(I,J,K ,2,0)	00239000
DZM1=ZL(I,J,KM1,2,0)	00239100
	00239200
C *** SURFACE LENGTH OF THE CONTROL VOLUME	00239300
	00239400
	00239500
DXN=XL(I,JP1,K,2,2)	00239600
DXS=XL(I,J ,K,2,2)	00239700
DXF=XL(I,J,KP1,2,3)	00239800
DXB=XL(I,J,K ,2,3)	00239900
	00240000
DYF=YL(I,J,KP1,2,3)	00240100
DYB=YL(I,J,K ,2,3)	00240200
DYE=YL(IP1,J,K,2,1)	00240300
DYW=YL(I ,J,K,2,1)	00240400
	00240500
DZE=ZL(IP1,J,K,2,1)	00240600
DZW=ZL(I ,J,K,2,1)	00240700
DZN=ZL(I,JP1,K,2,2)	00240800
DZS=ZL(I,J ,K,2,2)	00240900
	00241000
C *** CENTRAL LENGTH OF THE STAGGERED CONTROL VOLUME	00241100
	00241200
DXEE=XL(IP2,J,K,2,1)	00241300
DXE =XL(IP1,J,K,2,1)	00241400
DXW =XL(I ,J,K,2,1)	00241500
DXWW=XL(IM1,J,K,2,1)	00241600
	00241700
DYNN=YL(I,JP2,K,2,2)	00241800
DYN =YL(I,JP1,K,2,2)	00241900
DYS =YL(I,J ,K,2,2)	00242000
DYSS=YL(I,JM1,K,2,2)	00242100
	00242200
DZFF=ZL(I,J,KP2,2,3)	00242300
DZF =ZL(I,J,KP1,2,3)	00242400
DZB =ZL(I,J,K ,2,3)	00242500
DZBB=ZL(I,J,KM1,2,3)	00242600
	00242700
C *** DEFINE THE AREA OF THE CONTROL VOLUME	00242800
	00242900
DXYF=DXF*DYF	00243000
DXYB=DXB*DYB	00243100
DYZE=DYE*DZE	00243200
DYZW=DYW*DZW	00243300
DZXN=DZN*DXN	00243400
DZXS=DZS*DXS	00243500
	00243600
VOL=DXI*DYJ*DZK	00243700
VOLDT=VOL/DTIME	00243800
	00243900
ZXOYN=DZXN/DYN	00244000
ZXOYS=DZXS/DYS	

XYOZF=DXZF/DZF	00244100
XYOZB=DXZB/DZB	00244200
YZOXE=DYZE/DXE	00244300
YZOXW=DYZW/DXW	00244400
	00244500
	00244600
C *** USE SINGLE AND BI-LINEAR INTERPOLATION TO EVALUATE	00244700
C & PHYSICAL PROPERTIES AND FLUX ON THE SURFACES.	00244800
	00244900
	00245000
GEN=SILIN(R(IP1,J,K),R(I,J,K),DXP1,DXI)*U(IP1,J,K)	00245100
GES=SILIN(R(IP1,JM1,K),R(I,JM1,K),DXP1,DXI)*U(IP1,JM1,K)	00245200
GWN=SILIN(R(IM1,J,K),R(I,J,K),DXM1,DXI)*U(I,J,K)	00245300
GWS=SILIN(R(IM1,JM1,K),R(I,JM1,K),DXM1,DXI)*U(I,JM1,K)	00245400
	00245500
GN=SILIN(R(I,JP1,K),R(I,J,K),DYNN,DYN)*V(I,JP1,K)	00245600
GP=SILIN(R(I,JM1,K),R(I,J,K),DYS,DYN)*V(I,J,K)	00245700
GS=SILIN(R(I,JM2,K),R(I,JM1,K),DYSS,DYS)*V(I,JM1,K)	00245800
	00245900
GFN=SILIN(R(I,J,KP1),R(I,J,K),DZP1,DZK)*W(I,J,KP1)	00246000
GFS=SILIN(R(I,JM1,KP1),R(I,JM1,K),DZP1,DZK)*W(I,JM1,KP1)	00246100
GBN=SILIN(R(I,J,KM1),R(I,J,K),DZM1,DZK)*W(I,J,K)	00246200
GBS=SILIN(R(I,JM1,KM1),R(I,JM1,K),DZM1,DZK)*W(I,JM1,K)	00246300
	00246400
CN=0.5*(GN+GP)*DZXN	00246500
CS=0.5*(GP+GS)*DZXS	00246600
	00246700
CE=SILIN(GEN,GES,DYN,DYS)*DYZE	00246800
CW=SILIN(GWN,GWS,DYN,DYS)*DYZW	00246900
	00247000
CF=SILIN(GFN,GFS,DYN,DYS)*DXYF	00247100
CB=SILIN(GBN,GBS,DYN,DYS)*DXYB	00247200
	00247300
VISN=VIS(I,J,K)	00247400
VISS=VIS(I,JM1,K)	00247500
	00247600
WISE= (VIS(IP1,J,K)+VIS(I,J,K)+	00247700
& VIS(IP1,JM1,K)+VIS(I,JM1,K))/4.0	00247800
VISW= (VIS(IM1,J,K)+VIS(I,J,K)+	00247900
& VIS(IM1,JM1,K)+VIS(I,JM1,K))/4.0	00248000
	00248100
VISF= (VIS(I,J,KP1)+VIS(I,J,K)+	00248200
& VIS(I,JM1,KP1)+VIS(I,JM1,K))/4.0	00248300
VISB= (VIS(I,J,KM1)+VIS(I,J,K)+	00248400
& VIS(I,JM1,KM1)+VIS(I,JM1,K))/4.0	00248500
	00248600
	00248700
	00248800
VISN1=ZXOYN*VISN	00248900
VISS1=ZXOYS*VISS	00249000
VISE1=YZOXE*VISE	00249100
VISW1=YZOXW*VISW	00249200
VISF1=XYOZF*VISF	00249300
VISB1=XYOZB*VISB	00249400
	00249500
	00249600
C CEP=(ABS(CE)-C)*DXP1*DXI/(DXE*(DXE+DXW))/8.	00249700
CEM=(ABS(CE)-CE)*DXP1*DXI/(DXE*(DXE+DXEE))/8.	00249800
CWP=(ABS(CW)-CW)*DXM1*DXI/(DXW*(DXW+DXWW))/8.	00249900
CWM=(ABS(CW)-CW)*DXM1*DXI/(DXW*(DXW+DXE))/8.	00250000
	00250100
C CNP=(ABS(CN)+CN)*DYN/DYJ/16.	00250200
CNM=(ABS(CN)-CN)*DYN/DYJ/16.	00250300
CSP=(ABS(CS)-CS)*DYS/DYM/16.	00250400
CSM=(ABS(CS)-CS)*DYS/DYJ/16.	00250500
	00250600
	00250700
C CFP=(ABS(CF)-C)*DZP1*DZK/(DZF*(DZF+DZB))/8.	00250800

	CFM=(ABS(CF)-CF)*DZP1*DZK/(DZF*(DZF+DZFF))/8.	00250900
	CBP=(ABS(CB)+CB)*DZM1*DZK/(DZB*(DZB+DZBB))/8.	00251000
	CBM=(ABS(CB)-CB)*DZM1*DZK/(DZB*(DZB+DZFF))/8.	00251100
C		00251200
C		00251300
	AE(I,J,K)=-.5*DXI/DXE*CE+CEP+CEM*(1.+DXE/DXEE)+CWM*DXW/DXE+VISE1	00251400
	AW(I,J,K)=.5*DXI/DXW*CW+CWM+CWP*(1.+DXW/DXWW)+CEP*DXE/DXW+VISW1	00251500
C		00251600
	AN(I,J,K)=-.5*CN+CNP+CNM*(1.+DYN/DYNN)+CSM*DYS/DYN+VISN1	00251700
	AS(I,J,K)=.5*CS+CSM+CSP*(1.+DYS/DYSS)+CNP*DYN/DYS+VISS1	00251800
C		00251810
	AF(I,J,K)=-.5*DZK/DZF*CF+CFP+CFM*(1.+DZF/DZFF)+CBM*DZB/DZF+VISF1	00251820
	AB(I,J,K)=.5*DZK/DZB*CB+CBM+CBP*(1.+DZB/DZBB)+CFP*DZF/DZB+VISB1	00251830
C		00251840
	801 AEE=-CEM*DXE/DXEE	00251900
	AEER=AEE*VPD(IP2,J,K)	00252000
	802 CONTINUE	00252100
		00252200
	803 AWW=-CWP*DXW/DXWW	00252300
	AWWR=AWW*VPD(IM2,J,K)	00252400
	804 CONTINUE	00252500
		00252600
	IF (J.LT.NJ) GOTO 805	00252700
	ANN=0.	00252800
	ANNR=0.	00252900
	GOTO 806	00253000
	805 ANN=-CNM*DYN/DYNN	00253100
	ANNR=ANN*VPD(I,JP2,K)	00253200
	806 CONTINUE	00253300
		00253400
	IF (J.GT.3) GOTO 807	00253500
	ASS=0.	00253600
	ASSR=0.	00253700
	GOTO 808	00253800
	807 ASS=-CSP*DYS/DYSS	00253900
	ASSR=ASS*VPD(I,JP2,K)	00254000
	808 CONTINUE	00254100
		00254200
	IF (K.LT.NK) GOTO 809	00254300
	AFF=0.	00254400
	AFFR=0.	00254500
	GOTO 810	00254600
	809 AFF=-CFM*DZF/DZFF	00254700
	AFFR=AFF*VPD(I,J,KP2)	00254800
	810 CONTINUE	00254900
		00255000
	IF (K.GT.2) GOTO 811	00255100
	ABB=0.	00255200
	ABBR=0.	00255300
	GOTO 812	00255400
	811 ABB=-CBP*DZB/DZBB	00255500
	ABBR=ABB*VPD(I,J,KM2)	00255600
	812 CONTINUE	00255700
		00255800
		00255900
		00256000
		00256100
C	*****	00256200
C	*****	00256300
C	*** MODIFICATION FOR DECK BOUNDARIES	00256400
		00256500
	900 CONTINUE	00256600
	IF (NOD(IM1,J,K).EQ.0) GOTO 901	00256700
	AWW=0.0	00256800
	AWWR=0.0	00256900
		00257000
	901 CONTINUE	00257100
	IF (NOD(IP1,J,K).EQ.0) GOTO 902	00257200

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AEE=0.0
AER=0.0
902 CONTINUE
IF (NOD(I,JM2,K).EQ.0) GOTO 903
ASS=0.0
ASSR=0.0
903 CONTINUE
IF (NOD(I,JP1,K).EQ.0) GOTO 904
ANN=0.0
ANNR=0.0
904 CONTINUE
IF (NOD(I,J,KM1).EQ.0) GOTO 905
ABB=0.0
ABBR=0.0
905 CONTINUE
IF (NOD(I,J,KP1).EQ.0) GOTO 906
AFF=0.0
AFFR=0.0
906 CONTINUE

C *****
C *****

C *** SU FROM NORMAL STRESS
RN=(SIG22(I,J,K)-(V(I,JP1,K)-V(I,J,K))*VISN/DYN)*DZXN
RS=(SIG22(I,JM1,K)-(V(I,J,K)-V(I,JM1,K))*VISS/DYS)*DZXS
RE=(SIG12(IP1,J,K)-(V(IP1,J,K)-V(I,J,K))*VISE/DXE)*DYZE
RW=(SIG12(I,J,K)-(V(I,J,K)-V(IM1,J,K))*VISW/DXW)*DYZW
RF=(SIG23(I,J,KP1)-(V(I,J,KP1)-V(I,J,K))*VISF/DZF)*DXYF
RB=(SIG23(I,J,K)-(V(I,J,K)-V(I,J,KM1))*VISB/DZB)*DXYB

C *** SU FROM CURVED STRESSES AND ACCELERATIONS
AVG12=0.5*(SIG12(IP1,J,K)+SIG12(I,J,K))
AVG23=0.5*(SIG23(I,J,KP1)+SIG23(I,J,K))
AVG11=SILIN(SIG11(I,J,K),SIG11(I,JM1,K),DYN,DYS)
AVG33=SILIN(SIG33(I,J,K),SIG33(I,JM1,K),DYN,DYS)

AU2=V(I,J,K)
AU1=BILIN(U(IP1,J,K),U(I,J,K),DXI,DXI,
      U(IP1,JM1,K),U(I,JM1,K),DYN,DYS)
AU3=BILIN(W(I,J,KP1),W(I,J,K),DZK,DZK,
      W(I,JM1,KP1),W(I,JM1,K),DYN,DYS)

AR=SILIN(R(I,J,K),R(I,JM1,K),DYN,DYS)

ARU12=AR*AU1*AU2
ARU23=AR*AU2*AU3
ARU11=AR*AU1*AU1
ARU33=AR*AU3*AU3

RRX=(AVG12-ARU12)*DZK*(DYE-DYW)
RRZ=(AVG23-ARU23)*DXI*(DYF-DYB)
RRY=(AVG11-ARU11)*DZK*(DXN-DXS)+
      (AVG33-ARU33)*DXI*(DZN-DZS)

AP(I,J,K)=AE(I,J,K)+AW(I,J,K)+AN(I,J,K)-AS(I,J,K)
      -AF(I,J,K)+AB(I,J,K)+AEE-AWW-ANN+ASS+AFF-ABB
SP(I,J,K)=-(ROD(I,J,K)*DYS+ROD(I,JM1,K)*DYN)/(DYS-DYN)*VOLDT
SU(I,J,K)=-(ROD(I,J,K)*DYS+ROD(I,JM1,K)*DYN)/(DYS-DYN)*VOLDT

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&	*VOD(I,J,K)	00264100
		00264200
	SU(I,J,K)=SU(I,J,K)+DZK*DXI*(P(I,JM1,K)-P(I,J,K))	00264300
&	+AEER+AWWR+ANNR+ASSR+AFFR+ABBR	00264400
&	+RE-RW+RN-RS+RF-RB+RRX+RRZ-RRY	00264500
&	-BUOY*((R(I,J,K)-REQ(I,J,K))*DYS+(R(I,JM1,K)	00264600
&	-REQ(I,JM1,K))*DYN)/(DYS+DYN)*VOL*SIN(ZC(K))*SIN(XC(I))	00264700
100	CONTINUE	00264800
		00264900
		00265000
C ***	TAKE CARE OF B.C. THRU AN,AS,AE,AW,AF,AB,SP AND SU	00265100
C		00265200
C ***	RADIUS DIRECTION	00265300
		00265400
	DO 500 K=2,NK	00265500
	DO 500 I=2,NI	00265600
CC	SP(I,3,K)=SP(I,3,K)+AS(I,3,K)	00265700
	SU(I,3,K)=SU(I,3,K)+AS(I,3,K)*V(I,2,K)	00265800
	AS(I,3,K)=0.	00265900
	AN(I,NJ,K)=0.	00266000
500	CONTINUE	00266100
		00266200
C ***	CYCLIC CONDITIONS	00266300
		00266400
	DO 502 K=2,NK	00266500
	DO 502 J=3,NJ	00266600
	SU(2,J,K)=SU(2,J,K)+AW(2,J,K)*V(1,J,K)	00266700
	SU(NI,J,K)=SU(NI,J,K)+AE(NI,J,K)*V(NIP1,J,K)	00266800
	AW(2,J,K)=0.0	00266900
	AE(NI,J,K)=0.0	00267000
502	CONTINUE	00267100
		00267200
C ***	FRONT AND BACK WALL	00267300
		00267400
	DO 600 I=2,NI	00267500
	DO 600 J=3,NJ	00267600
	JM1=J-1	00267700
		00267800
C ***	SLIP WALLS	00267900
	SP(I,J,2)=SP(I,J,2)+AB(I,J,2)	00268000
	SP(I,J,NK)=SP(I,J,NK)+AF(I,J,NK)	00268100
		00268200
	AF(I,J,NK)=0.	00268300
	AB(I,J,2)=0.	00268400
600	CONTINUE	00268500
		00268600
		00268700
		00268800
C *****		00268900
C ***	MODIFICATION FOR DECK BOUNDARIES	00269000
		00269100
	DO 101 N=1,NCHIP	00269200
	IB=ICHPB(N)	00269300
	IE=IB+NCHIP(N)-1	00269400
	IBM1=IB-1	00269500
	IEP1=IE-1	00269600
	JB=JCHPB(N)	00269700
	JE=JB+NCHPB(N)-1	00269800
	IBM1=JB-1	00269900
	IEP1=JE-1	00270000
	KB=KCHPB(N)	00270100
	KE=KB+NCHPB(N)-1	00270200
	KBM1=KB-1	00270300
	KEP1=KE-1	00270400
		00270500
	DO 102 J=JB,JE	00270600
	DO 102 K=KB,KE-1	00270700
	SP(IBM1,J,K)=SP(IBM1,J,K)-AE(IBM1,J,K)	00270800

AE(IE,J,K)=0.0	00270900
SP(IE,J,K)=SP(IE,J,K)-AW(IE,J,K)	00271000
AW(IE,J,K)=0.0	00271100
102 CONTINUE	00271200
DO 103 I=IB,IE-1	00271300
DO 103 K=KB,KE-1	00271400
AN(I,JBM1,K)=0.0	00271500
AS(I,JEP1,K)=0.0	00271600
103 CONTINUE	00271700
DO 106 I=IB,IE-1	00271800
DO 106 J=JB,JE	00271900
SP(I,J,KBM1)=SP(I,J,KBM1)-AF(I,J,KBM1)	00272000
AF(I,J,KBM1)=0.0	00272100
SP(I,J,KE)=SP(I,J,KE)-AB(I,J,KE)	00272200
AB(I,J,KE)=0.0	00272300
106 CONTINUE	00272400
	00272500
	00272600
	00272700
	00272800
	00272900
	00273000
C *****	00273100
C *****	00273200
C *** MODIFICATION FOR THE CELLS INSIDE OF THE DECKS	00273300
DO 104 I=IB,IE-1	00273400
DO 104 J=JB,JE	00273500
DO 104 K=KB,KE-1	00273600
SP(I,J,K)=-1.0E20	00273700
AW(I,J,K)=0.	00273800
AE(I,J,K)=0.	00273900
AS(I,J,K)=0.	00274000
AN(I,J,K)=0.	00274100
SU(I,J,K)=0.	00274200
104 CONTINUE	00274300
101 CONTINUE	00274400
105 CONTINUE	00274500
	00274600
	00274700
	00274800
	00274900
C *****	00275000
C *****	00275100
C	00275200
C *** ASSEMBLE COEFFICIENTS AND SOLVE DIFFERENCE EQUATIONS	00275300
DO 300 K=2,NK	00275400
DO 300 J=3,NJ	00275500
DO 300 I=2,NI	00275600
DXI=XI(I,J,K,2,0)	00275700
DZK=Z(I,J,K,2,0)	00275800
DZX=DZK*DXI	00275900
AP(I,J,K)=AP(I,J,K)-SP(I,J,K)	00276000
DV(I,J,K)=DZX/AP(I,J,K)	00276100
300 CONTINUE	00276200
	00276300
	00276400
	00276500
C *** SOLVE FOR V	00276600
	00276700
	00276800
CALL TRID (2,3,2,NI,NJ,NK,V)	00276900
	00277000
	00277100
DO 74 I=2,NIP1	00277200
DO 74 J=2,NJP1	00277300
V(I,J,1)=V(I,J,0)	00277400
V(I,J,NXP1)=V(I,J,NK)	00277500
74 CONTINUE	00277600

DO 100 K=3,NK	00284400
KP2=K+2	00284500
KP1=K+1	00284600
KM1=K-1	00284700
KM2=K-2	00284800
DO 100 J=2,NJ	00284900
JP2=J+2	00285000
JP1=J+1	00285100
JM1=J-1	00285200
JM2=J-2	00285300
DO 100 I=2,NI	00285400
IP2=I+2	00285500
IP1=I+1	00285600
IM1=I-1	00285700
IM2=I-2	00285800
IF (I.EQ.2) IM2=NIM1	00285900
IF (I.EQ.NI) IP2=3	00286000
	00286100
	00286200
C CENTRAL LENGTH OF THE SCALE CONTROL VOLUME	00286300
DXP1=XL(IP1,J,K,3,0)	00286400
DXI =XL(I ,J,K,3,0)	00286500
DXM1=XL(IM1,J,K,3,0)	00286600
	00286700
	00286800
DYP1=YL(I,JP1,K,3,0)	00286900
DYJ =YL(I,J ,K,3,0)	00287000
DYM1=YL(I,JM1,K,3,0)	00287100
	00287200
DZP1=ZL(I,J,KP1,3,0)	00287300
DZK =ZL(I,J,K ,3,0)	00287400
DZM1=ZL(I,J,KM1,3,0)	00287500
	00287600
C *** SURFACE LENGTH OF THE CONTROL VOLUME	00287700
	00287800
DXN=XL(I,JP1,K,3,2)	00287900
DXS=XL(I,J ,K,3,2)	00288000
DXF=XL(I,J,KP1,3,3)	00288100
DXB=XL(I,J,K ,3,3)	00288200
	00288300
DYF=YL(I,J,KP1,3,3)	00288400
DYB=YL(I,J,K ,3,3)	00288500
DYE=YL(IP1,J,K,3,1)	00288600
DYW=YL(I ,J,K,3,1)	00288700
	00288800
DZE=ZL(IP1,J,K,3,1)	00288900
DZW=ZL(I ,J,K,3,1)	00289000
DZN=ZL(I,JP1,K,3,2)	00289100
DZS=ZL(I,J ,K,3,2)	00289200
	00289300
C *** CENTRAL LENGTH OF THE STAGGERED CONTROL VOLUME	00289400
	00289500
DXEE=XL(IP2,J,K,3,1)	00289600
DXE =XL(IP1,J,K,3,1)	00289700
DXW =XL(I ,J,K,3,1)	00289800
DXWW=XL(IM1,J,K,3,1)	00289900
	00290000
DYNN=YL(I,JP2,K,3,2)	00290100
DYN =YL(I,JP1,K,3,2)	00290200
DYS =YL(I,J ,K,3,2)	00290300
DYSS=YL(I,JM1,K,3,2)	00290400
	00290500
DZFF=ZL(I,J,KP2,3,3)	00290600
DZF =ZL(I,J,KP1,3,3)	00290700
DZB =ZL(I,J,K ,3,3)	00290800
DZBB=ZL(I,J,KM1,3,3)	00290900
	00291000
C *** DEFINE THE AREA OF THE CONTROL VOLUME	00291100

DXZF=DXF*DYF
 DXYB=DXB*DYB
 DYZE=DYE*DZE
 DYZW=DYW*DZW
 DZXN=DZN*DXN
 DZXS=DZS*DXS

VOL=DXI*DYJ*DZK
 VOLCT=VOL/DTIME

ZXOYN=ZXN/DYN
 ZXOYS=ZXS/DYS
 XYOZF=DXZF/DZF
 XYOZB=DXYB/DZB
 YZOXE=DYZE/DXE
 YZOXW=DYZW/DXW

C *** USE SINGLE AND BI-LINEAR INTERPOLATION TO EVALUATE
 C 4 PHYSICAL PROPERTIES AND FLUX ON THE SURFACES.

GNF=SILIN(R(I,JP1,K),R(I,J,K),DYP1,DYJ)*V(I,JP1,K)
 GNB=SILIN(R(I,JP1,KM1),R(I,J,KM1),DYP1,DYJ)*V(I,JP1,KM1)
 GSF=SILIN(R(I,JM1,K),R(I,J,K),DYM1,DYJ)*V(I,J,K)
 GSB=SILIN(R(I,JM1,KM1),R(I,J,KM1),DYM1,DYJ)*V(I,J,KM1)

GF=SILIN(R(I,J,KP1),R(I,J,K),DZFF,DZF)*W(I,J,KP1)
 GP=SILIN(R(I,J,KM1),R(I,J,K),DZB,DZF)*W(I,J,K)
 GB=SILIN(R(I,J,KM2),R(I,J,KM1),DZBB,DZB)*W(I,J,KM1)

GEF=SILIN(R(IP1,J,K),R(I,J,K),DXP1,DXI)*U(IP1,J,K)
 GEB=SILIN(R(IP1,J,KM1),R(I,J,KM1),DXP1,DXI)*U(IP1,J,KM1)
 GWF=SILIN(R(IM1,J,K),R(I,J,K),DXM1,DXI)*U(I,J,K)
 GWB=SILIN(R(IM1,J,KM1),R(I,J,KM1),DXM1,DXI)*U(I,J,KM1)

CF=0.5*(GF+GP)*DXZF
 CB=0.5*(GP+GB)*DXYB

CN=SILIN(GNF,GNB,DZF,DZB)*DZXN
 CS=SILIN(GSF,GSB,DZF,DZB)*DZXS

CE=SILIN(GEF,GEB,DZF,DZB)*DYZE
 CW=SILIN(GWF,GWB,DZF,DZB)*DYZW

VISF=VIS(I,J,K)
 VISB=VIS(I,J,KM1)

VISN=(VIS(I,JP1,K)-VIS(I,J,K))+
 4 VIS(I,JP1,KM1)+VIS(I,J,KM1))/4.0
 VISS=(VIS(I,JM1,K)-VIS(I,J,K))+
 4 VIS(I,JM1,KM1)+VIS(I,J,KM1))/4.0

VISE=(VIS(IP1,J,K)+VIS(I,J,K))+
 4 VIS(IP1,J,KM1)+VIS(I,J,KM1))/4.0
 VISW=(VIS(IM1,J,K)+VIS(I,J,K))+
 4 VIS(IM1,J,KM1)+VIS(I,J,KM1))/4.0

VISN1=ZXOYN*VISN
 VISS1=ZXOYS*VISS
 VISE1=YZOXE*VISE
 VISW1=YZOXW*VISW
 VISF1=XYOZF*VISF
 VISB1=XYOZB*VISB

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C

	CEP=(ABS(CE)+CE)*DXP1*DXI/(DXE*(DXE+DXW))/8.	00298000
	CEM=(ABS(CE)-CE)*DXP1*DXI/(DXE*(DXE+DXE))/8.	00298100
	CWP=(ABS(CW)+CW)*DXM1*DXI/(DXW*(DXW+DXWW))/8.	00298200
	CWM=(ABS(CW)-CW)*DXM1*DXI/(DXW*(DXW+DXE))/8.	00298300
C		00298400
	CNP=(ABS(CN)+CN)*DYP1*DYJ/(DYN*(DYN+DYS))/8.	00298500
	CNM=(ABS(CN)-CN)*DYP1*DYJ/(DYN*(DYN+DYN))/8.	00298600
	CSP=(ABS(CS)+CS)*DYM1*DYJ/(DYS*(DYS+DYSS))/8.	00298700
	CSM=(ABS(CS)-CS)*DYM1*DYJ/(DYS*(DYS+DYN))/8.	00298800
C		00298900
C		00299000
	CFP=(ABS(CF)+CF)*DZF/DZK/16.	00299100
	CFM=(ABS(CF)-CF)*DZF/DZP1/16.	00299200
	CBP=(ABS(CB)+CB)*DZB/DZM1/16.	00299300
	CBM=(ABS(CB)-CB)*DZB/DZK/16.	00299400
C		00299500
	AE(I,J,K)=-.5*DXI/DXE*CE+CEP+CEM*(1.+DXE/DXEE)+CWM*DXW/DXE+VISE1	00299600
	AM(I,J,K)=.5*DXI/DXW*CW+CWM+CWP*(1.+DXW/DXWW)+CEP*DXE/DXW+VISW1	00299700
	AN(I,J,K)=-.5*DYJ/DYN*CN+CNP+CNM*(1.+DYN/DYNN)+CSM*DYS/DYN+VISN1	00299800
	AS(I,J,K)=.5*DYJ/DYS*CS+CSM+CSP*(1.+DYS/DYSS)+CNP*DYN/DYS+VISS1	00299900
C		00300000
	AF(I,J,K)=-.5*CF+CFP+CFM*(1.+DZF/DZFF)+CBM*DZB/DZF+VISF1	00300100
C		00300110
	AB(I,J,K)=.5*CB+CBM+CBP*(1.+DZB/DZBB)+CFP*DZF/DZB+VISB1	00300120
		00300200
801	AEE=-CEM*DXE/DXEE	00300300
	AEE=AEE*WPD(IP2,J,K)	00300400
802	CONTINUE	00300500
		00300600
803	AWW=-CWP*DXW/DXWW	00300700
	AWW=AWW*WPD(IM2,J,K)	00300800
804	CONTINUE	00300900
		00301000
	IF (J.LT.NJ) GOTO 805	00301100
	ANN=0.	00301200
	ANNR=0.	00301300
	GOTO 806	00301400
805	ANN=-CNM*DYN/DYNN	00301500
	ANNR=ANN*WPD(I,J2,K)	00301600
806	CONTINUE	00301700
		00301800
	IF (J.GT.2) GOTO 807	00301900
	ASS=0.	00302000
	ASSR=0.	00302100
	GOTO 808	00302200
807	ASS=-CSP*DYS/DYSS	00302300
	ASSR=ASS*WPD(I,J2,K)	00302400
808	CONTINUE	00302500
		00302600
	IF (K.LT.NK) GOTO 809	00302700
	AFF=0.	00302800
	AFFR=0.	00302900
	GOTO 810	00303000
809	AFF=-CFM*DZF/DZFF	00303100
	AFFR=AFF*WPD(I,J,K2)	00303200
810	CONTINUE	00303300
		00303400
	IF (K.GT.3) GOTO 811	00303500
	ABB=0.	00303600
	ABBR=0.	00303700
	GOTO 812	00303800
811	ABB=-CBP*DZB/DZBB	00303900
	ABBR=ABB*WPD(I,J,K2)	00304000
812	CONTINUE	00304100
		00304200
		00304300
C	*****	00304400
C	*****	00304500

C *** MODIFICATION FOR DECK BOUNDARIES

900 CONTINUE
IF (NOD(IM1,J,K).EQ.0) GOTO 901
AWW=0.0
AWWR=0.0

901 CONTINUE
IF (NOD(IP1,J,K).EQ.0) GOTO 902
AEE=0.0
AEER=0.0

902 CONTINUE
IF (NOD(I,JM1,K).EQ.0) GOTO 903
ASS=0.0
ASSR=0.0

903 CONTINUE
IF (NOD(I,JP1,K).EQ.0) GOTO 904
ANN=0.0
ANNR=0.0

904 CONTINUE
IF (NOD(I,J,KM2).EQ.0) GOTO 905
ABB=0.0
ABBR=0.0

905 CONTINUE
IF (NOD(I,J,KP1).EQ.0) GOTO 906
AFF=0.0
AFFR=0.0

906 CONTINUE

C #####

C #####

C *** SU FROM NORMAL STRESS

RF=(SIG33(I,J,K)-(W(I,J,KP1)-W(I,J,K))*VISE/DZF)*DXYF
RB=(SIG33(I,J,KM1)-(W(I,J,K)-(W(I,J,KM1))*VISB/DZB)*DXYB
RN=(SIG23(I,JP1,K)-(W(I,JP1,K)-W(I,J,K))*VISN/DYN)*DZXN
RS=(SIG23(I,J,K)-(W(I,J,K)-W(I,JM1,K))*VISS/DYS)*DZXS
RE=(SIG13(IP1,J,K)-(W(IP1,J,K)-W(I,J,K))*VISE/DXE)*DYZE
RW=(SIG13(I,J,K)-(W(I,J,K)-W(IM1,J,K))*VISW/DXW)*DYZW

C *** SU FROM CURVED STRESSES AND ACCELERATIONS

AVG23=0.5*(SIG23(I,JP1,K)+SIG23(I,J,K))
AVG13=0.5*(SIG13(IP1,J,K)+SIG13(I,J,K))
AVG22=SILIN(SIG22(I,J,K),SIG22(I,J,KM1),DZF,DZB)
AVG11=SILIN(SIG11(I,J,K),SIG11(I,J,KM1),DZF,DZB)

AU3=W(I,J,K)
AU2=BILIN(V(I,JP1,K),V(I,J,K),DYJ,DYJ,
& V(I,JP1,KM1),V(I,J,KM1),DYJ,DYJ,DZF,DZB)
AU1=BILIN(U(IP1,J,K),U(I,J,K),DXI,DXI,
& U(IP1,J,KM1),U(I,J,KM1),DXI,DXI,DZF,DZB)

AR=SILIN(R(I,J,K),R(I,J,KM1),DZF,DZB)

ARU23=AR*AU2*AU3
ARU13=AR*AU1*AU3
ARU22=AR*AU2*AU2
ARU11=AR*AU1*AU1

RRY=(AVG23-ARU23)*DXI*(DZN-DZS)
RRX=(AVG13-ARU13)*DYJ*(DZE-DZW)

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PRZ=(AVG22-ARU22)*DXI*(DYF-DYB)+
& (AVG11-ARU11)*DYJ*(DXF-DXB)

AP(I,J,K)=AE(I,J,K)+AW(I,J,K)+AN(I,J,K)+AS(I,J,K)
& +AF(I,J,K)+AB(I,J,K)+AEE+AWW+ANN+ASS+AFF+ABB
SP(I,J,K)=-(ROD(I,J,K)*DZB+ROD(I,J,KM1)*DZF)/(DZB+DZF)*VOLDT
SU(I,J,K)=(ROD(I,J,K)*DZB+ROD(I,J,KM1)*DZF)/(DZB+DZF)*VOLDT
& *WOD(I,J,K)
SU(I,J,K)=SU(I,J,K)+DXI*DYJ*(P(I,J,KM1)-P(I,J,K))
& +AEER+AWWR+ANNR+ASSR+AFRR+ABBR
& +RE-RW+RN-RS+RF-RB+RRY+RRX+RRZ
& -SUOY*((R(I,J,K)-REQ(I,J,K))*DZB*COS(ZC(K)))+(R(I,J,
& KM1)-REQ(I,J,KM1))*DZF*COS(ZC(KM1)))/(DZB+DZF)*VOL*SIN(XC(I))
100 CONTINUE

C *** TAKE CARE OF B.C. THRU AN,AS,AE,AW,AP AND SU
C
C *** RADIUS DIRECTION

DO 500 K=3,NK
DO 500 I=2,NI
KM1=K-1
CC SP(I,2,K)=SP(I,2,K)+AS(I,2,K)
SP(I,2,K)=SP(I,2,K)-AS(I,2,K)
SU(I,2,K)=SU(I,2,K)+2.0*W(I,1,K)*AS(I,2,K)
SP(I,NJ,K)=SP(I,NJ,K)-AN(I,NJ,K)
AS(I,2,K)=0.
AN(I,NJ,K)=0.
500 CONTINUE

C *** CYLIC CONDITIONS

DO 502 K=3,NK
DO 502 J=2,NJ
SU(2,J,K)=SU(2,J,K)+AW(2,J,K)*W(1,J,K)
SU(NI,J,K)=SU(NI,J,K)+AE(NI,J,K)*W(NIPI,J,K)
AW(2,J,K)=0.0
AE(NI,J,K)=0.0
502 CONTINUE

C *** FRONT AND BACK WALL

DO 600 I=2,NI
DO 600 J=2,NJ
SP(I,J,NK)=SP(I,J,NK)+AF(I,J,NK)
SP(I,J,3)=SP(I,J,3)-AB(I,J,3)
AF(I,J,NK)=0.
AB(I,J,3)=0.
600 CONTINUE

IF (NCHIP.EQ.0) GOTO 105

C *****
C *****
C *** MODIFICATION FOR DECK BOUNDARIES

DO 101 N=1,NCHIP
IB=ICHPB(N)
IE=IB-NCHPI(N)-1
IM1=IB-1
IEPI=IE-1
JB=JCHPB(N)
JE=JB-NCHPJ(N)-1
JBM1=JB-1
JEP1=JE-1
YB=KCHPB(N)
YE=KB-NCHPK(N)-1

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KBM1=KB-1	00318200
KEP1=KE+1	00318300
	00318400
	00318493
DO 102 J=JB,JE-1	00318500
DO 102 K=KB,KE	00318600
SP(IBM1,J,K)=SP(IBM1,J,K)-AE(IBM1,J,K)	00318700
SU(IBM1,J,K)=SU(IBM1,J,K)+AE(IBM1,J,K)*WFAN(N)*2.0	00318710
AE(IBM1,J,K)=0.0	00318800
	00318900
	00319000
SP(IE,J,K)=SP(IE,J,K)-AW(IE,J,K)	00319100
SU(IE,J,K)=SU(IE,J,K)+AW(IE,J,K)*WFAN(N)*2.0	00319110
AW(IE,J,K)=0.0	00319200
	00319300
102 CONTINUE	00319400
	00319500
DO 103 I=IB,IE-1	00319600
DO 103 K=KB,KE	00319700
SP(I,JBM1,K)=SP(I,JBM1,K)-AN(I,JBM1,K)	00319800
SU(I,JBM1,K)=SU(I,JBM1,K)+AN(I,JBM1,K)*WFAN(N)*2.0	00319810
AN(I,JBM1,K)=0.0	00319900
	00320000
SP(I,JE,K)=SP(I,JE,K)-AS(I,JE,K)	00320100
SU(I,JE,K)=SU(I,JE,K)+AS(I,JE,K)*WFAN(N)*2.0	00320110
AS(I,JE,K)=0.0	00320200
103 CONTINUE	00320300
	00320400
DO 106 I=IB,IE-1	00320500
DO 106 J=JB,JE-1	00320600
SU(I,J,KBM1)=SU(I,J,KBM1)+AF(I,J,KBM1)*WFAN(N)	00320610
SU(I,J,KEP1)=SU(I,J,KEP1)+AB(I,J,KEP1)*WFAN(N)	00320620
AF(I,J,KBM1)=0.0	00320700
AB(I,J,KEP1)=0.0	00320800
106 CONTINUE	00320900
C *** FOR THE CELLS INSIDE OF THE DECKS	00321000
	00321100
DO 104 I=IB,IE-1	00321200
DO 104 J=JB,JE-1	00321300
DO 104 K=KB,KE	00321400
SP(I,J,K)=-1.0E2	00321500
AW(I,J,K)=0.	00321600
AE(I,J,K)=0.	00321700
AS(I,J,K)=0.	00321800
AN(I,J,K)=0.	00321900
AB(I,J,K)=0.	00322000
AF(I,J,K)=0.	
SU(I,J,K)=1.0E2 * WFAN(N)	00322100
104 CONTINUE	00322200
101 CONTINUE	00322300
105 CONTINUE	00322400
	00322500
C *****	00322600
C *****	00322700
	00322800
	00322900
C *** ASSEMBLE COEFFICIENTS AND SOLVE DIFFERENCE EQUATIONS	00323000
	00323100
	00323200
DO 301 K=3,NK	00323300
DO 301 J=2,NJ	00323400
DO 301 I=2,NI	00323500
DXI=XI(I,J,K,3,0)	00323600
DYJ=YI(I,J,K,3,0)	00323700
DXY=DXI*DYJ	00323800
AP(I,J,K)=AP(I,J,K)-SP(I,J,K)	00323900
DW(I,J,K)=DXY/AP(I,J,K)	00324000

301 CONTINUE	00324100
	00324200
C *** SOLVE FOR W	00324300
	00324400
CALL TRID (2,2,3,NI,NJ,NK,W)	00324500
	00324600
C	00324700
DO 76 I=1,NI	00324800
DO 76 J=1,NJ	00324900
W(I,J,2)=W(I,J,3)	00325000
W(I,J,NKP1)=W(I,J,NK)	00325100
76 CONTINUE	00325200
	00325300
	00325400
	00325500
IF (NCHIP.EQ.0) GOTO 112	00325600
C #####	00325700
C #####	00325800
C *** RESET THE VELOCITY INSIDE OF THE DECKS	00325900
	00326000
DO 110 N=1,NCHIP	00326100
IB=ICHPB(N)	00326200
IE=IB+NCHPI(N)-1	00326300
JB=JCHPB(N)	00326400
JE=JB+NCHPJ(N)-1	00326500
KB=KCHPB(N)	00326600
KE=KB+NCHPK(N)-1	00326700
DO 108 I=IB,IE-1	00326800
DO 108 J=JB,JE-1	00326900
DO 108 K=KB,KE	00327000
W(I,J,K)=WFAN(N)	00327100
108 CONTINUE	00327200
110 CONTINUE	00327300
112 CONTINUE	00327400
	00327500
RETURN	00327600
END	00327700
	00327800
	00327900
C	00328000
C	00328100
C	00328200
-----	00328300
SUBROUTINE CALP	00328400
-----	00328500
C	00328600
COMMON/R4/XC(93),YC(93),ZC(93),XS(93),YS(93),ZS(93),	00328700
& DXXC(93),DYXC(93),DZZC(93),DXXS(93),DYYS(93),DZZS(93)	00328800
COMMON/BL1/DX,DY,DZ,VOL,DTIME,VOLDT,THOT,TCOOL,P1,Q,QR	00328900
COMMON/BL7/NI,NIP1,NIM1,NJ,NJP1,NJM1,NK,NKP1,NKM1	00329000
& ,NIP2,NJP2,NKP2,NA,NAP1,NAM1,NB,NBP1,NBM1,KRUN,NCHIP,NJRA,NWRP	00329100
COMMON/BL12/ NWRITE,NTAPE,NTMAX0,NTREAL,TIME,SORSUM,ITER	00329200
COMMON/BL16/ CONST1,CONST2,CONST3,CONST4,CONST6,NT,UG,UGRT,BUOY,	00329300
& CPO,PRT,CONDC,VISC,RH00,HR,TR,TA,DTEMP,TWRITE,TTAPE,TMAX,GC,RAIRO	00329400
COMMON/BL22/ICHPB(10),NCHPI(10),JCHPB(10),NCHPJ(10),KCHPB(10),	00329500
& NCHPK(10),TCHP(10),CPS(10),CONS(10),WFAN(10)	00329600
COMMON/BL31/ TOD(22,16,32),ROD(22,16,32),POD(22,16,32)	00329700
& ,COD(22,16,32),UOD(22,16,32),VOD(22,16,32),WOD(22,16,32)	00329800
COMMON/BL32/ T(22,16,32),R(22,16,32),P(22,16,32)	00329900
& ,C(22,16,32),U(22,16,32),V(22,16,32),W(22,16,32)	00330000
COMMON/BL33/ TPD(22,16,32),RPD(22,16,32),PPD(22,16,32)	00330100
& ,CPD(22,16,32),UPD(22,16,32),VPD(22,16,32),WPD(22,16,32)	00330200
COMMON/BL34/ HEIGHT(22,16,32),REQ(22,16,32),	00330300
& SMP(22,16,32),SMPP(22,16,32),PP(22,16,32),	00330400
& DU(22,16,32),DV(22,16,32),DW(22,16,32)	00330500
COMMON/BL36/AP(22,16,32),AE(22,16,32),AW(22,16,32),AN(22,16,32),	00330600
& AS(22,16,32),AF(22,16,32),AB(22,16,32),	00330700
& SP(22,16,32),SU(22,16,32),RI(22,16,32)	00330800
COMMON/BL37/ VIS(22,16,32),COND(22,16,32),NOD(22,16,32),RWALL(579)	00330900
& ,CPM(22,16,32),HSZ(3,2),NHSZ(22,16,32),RESORM(93)	00331000

C *** CALCULATE COEFFICIENTS

```
DO 100 K=2,NK
KP2=K-2
KP1=K-1
KM1=K-1
KM2=K-2
DO 100 J=2,NJ
JP2=J-2
JP1=J-1
JM1=J-1
JM2=J-2
DO 100 I=2,NI
IP2=I-2
IP1=I-1
IM1=I-1
IM2=I-2
IF (I.EQ.NI) IP1=2
```

C CENTRAL LENGTH OF THE SCALE CONTROL VOLUME

```
DXP1=XL(IP1,J,K,0,0)
DXI =XL(I ,J,K,0,0)
DXM1=XL(IM1,J,K,0,0)

DYP1=YL(I,JP1,K,0,0)
DYJ =YL(I,J ,K,0,0)
DYM1=YL(I,JM1,K,0,0)

DZP1=ZL(I,J,KP1,0,0)
DZK =ZL(I,J,K ,0,0)
DZM1=ZL(I,J,KM1,0,0)
```

C *** SURFACE LENGTH OF THE CONTROL VOLUME

```
DXN=XL(I,JP1,K,0,2)
DXS=XL(I,J ,K,0,2)
DXF=XL(I,J,KP1,0,3)
DXB=XL(I,J,K ,0,3)

DYF=YL(I,J,KP1,0,3)
DYB=YL(I,J,K ,0,3)
DYE=YL(IP1,J,K,0,1)
DYN=YL(I ,J,K,0,1)

DZE=ZL(IP1,J,K,0,1)
DZN=ZL(I ,J,K,0,1)
DZP=ZL(I,JP1,K,0,2)
DZS=ZL(I,J ,K,0,2)
```

C *** DEFINE AREA OF THE CONTROL VOLUME

```
DXYF=DXF*DYF
DXYB=DXB*DYB
DYZE=DYE*DZE
DYZW=DYW*DZW
DZXN=DZN*DXN
DZXS=DZS*DXS

VOL=DXI*DYJ*DZK
VOLDT=VOL/DTIME

RN=(R(I,J,K)*DYP1+R(I,JP1,K)*DYJ)/(DYP1-DYJ)
RS=(R(I,J,K)*DYM1+R(I,JM1,K)*DYJ)/(DYM1-DYJ)
RE=(R(I,J,K)*DXP1+R(IP1,J,K)*DXI)/(DXP1-DXI)
RW=(R(I,J,K)*DXM1+R(IM1,J,K)*DXI)/(DXM1-DXI)
```

00330900
00331000
00331100
00331200
00331300
00331400
00331500
00331600
00331700
00331800
00331900
00332000
00332100
00332200
00332300
00332400
00332500
00332600
00332700
00332800
00332900
00333000
00333100
00333200
00333300
00333400
00333500
00333600
00333700
00333800
00333900
00334000
00334100
00334200
00334300
00334400
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00337000
00337100
00337200
00337300
00337400
00337500
00337600

RF=(R(I,J,K)*DZP1+R(I,J,KP1)*DZK)/(DZP1+DZK)	00337700
RB=(R(I,J,K)*DZM1+R(I,J,KM1)*DZK)/(DZM1+DZK)	00337800
C *** DU ON VERTICAL WALLS AND DV ON HORIZONTAL WALLS ARE ZERO	00337900
AN(I,J,K)=RN*DZXN*DV(I,JP1,K)	00338000
AS(I,J,K)=RS*DZXS*DV(I,J,K)	00338100
AE(I,J,K)=RE*DYZE*DU(IP1,J,K)	00338200
AW(I,J,K)=RW*DYZW*DU(I,J,K)	00338300
AF(I,J,K)=RF*DXYF*DW(I,J,KP1)	00338400
AB(I,J,K)=RB*DXYB*DW(I,J,K)	00338500
	00338600
	00338700
	00338800
CN=RN*V(I,JP1,K)*DZXN	00338900
CS=RS*V(I,J,K)*DZXS	00339000
CE=RE*U(IP1,J,K)*DYZE	00339100
CW=RW*U(I,J,K)*DYZW	00339200
CF=RF*W(I,J,KP1)*DXYF	00339300
CB=RB*W(I,J,K)*DXYB	00339400
	00339500
SMP(I,J,K)=-(R(I,J,K)-ROD(I,J,K))*VOL/DTIME-CE+CW-CN+CS-CF+CB	00339600
C SMP(I,J,K)=-CE+CW-CN+CS-CF+CB	00339700
SU(I,J,K)=SMP(I,J,K)	00339800
SP(I,J,K)=0.	00339900
100 CONTINUE	00340000
	00340100
C *** TAKE CARE OF B.C. THRU AN,AS,AE,AW,AF,AB,SP AND SU	00340200
C	00340300
C *** RADIUS DIRECTION	00340400
	00340500
DO 500 K=2,NK	00340600
DO 500 I=2,NI	00340700
AS(I,2,K)=0.	00340800
AN(I,NJ,K)=0.	00340900
500 CONTINUE	00341000
	00341100
C *** LEFT WALL AND RIGHT WALL	00341200
	00341300
DO 501 K=2,NK	00341400
DO 501 J=2,NJ	00341500
C AW(2,J,K)=0.	00341600
C AE(NI,J,K)=0.	00341700
501 CONTINUE	00341800
	00341900
C *** FRONT AND BACK WALL	00342000
	00342100
DO 502 I=2,NI	00342200
DO 502 J=2,NJ	00342300
AB(I,J,2)=0.0	00342400
AF(I,J,NK)=0.0	00342500
502 CONTINUE	00342600
	00342700
	00342800
	00342900
	00343000
IF (NCHIP.EQ.0) GOTO 105	00343100
	00343200
C *****	00343300
C *****	00343400
C *** MODIFICATION FOR DECK BOUNDARIES	00343500
	00343600
DO 101 N=1,NCHIP	00343700
IB=ICHPB(N)	00343800
IE=IB-NCHPI(N)-1	00343900
IBM1=IB-1	00344000
IEP1=IE-1	00344100
JB=JCHPB(N)	00344200
JE=JB-NCHPJ(N)-1	00344300
IBM1=JB-1	00344400

JEP1=JE-1	00344500
KB=KCHPB(N)	00344600
KE=KB+NCHPK(N)-1	00344700
KBM1=KB-1	00344800
KEP1=KE+1	00344900
DO 102 J=JB,JE-1	00345000
DO 102 K=KB,KE-1	00345100
AE(IBM1,J,K)=0.0	00345200
AW(IE,J,K)=0.0	00345300
102 CONTINUE	00345400
	00345500
	00345600
	00345700
DO 103 I=IB,IE-1	00345800
DO 103 K=KB,KE-1	00345900
AN(I,JBM1,K)=0.0	00346000
AS(I,J,K)=0.0	00346100
103 CONTINUE	00346200
	00346300
DO 106 I=IB,IE-1	00346400
DO 106 J=JB,JE-1	00346500
AF(I,J,KBM1)=0.0	00346600
AB(I,J,KE)=0.0	00346700
106 CONTINUE	00346800
	00346900
C *** FOR THE CELLS INSIDE OF THE DECKS	00347000
	00347100
DO 104 I=IB,IE-1	00347200
DO 104 J=JB,JE-1	00347300
DO 104 K=KB,KE-1	00347400
SP(I,J,K)=-1.0E20	00347500
AW(I,J,K)=0.	00347600
AE(I,J,K)=0.	00347700
AS(I,J,K)=0.	00347800
AN(I,J,K)=0.	00347900
SU(I,J,K)=0.	00348000
104 CONTINUE	00348100
101 CONTINUE	00348200
105 CONTINUE	00348300
	00348400
	00348500
C *****	00348600
C *****	00348700
	00348800
	00348900
	00349000
C *** ASSEMBLE COEFFICIENTS AND SOLVE DIFFERENCE EQUATIONS	00349100
	00349200
DO 300 J=2,NJ	00349300
DO 300 I=2,NI	00349400
DO 300 K=2,NK	00349500
AP(I,J,K)=AN(I,J,K)+AS(I,J,K)+AE(I,J,K)+AW(I,J,K)-SP(I,J,K)	00349600
6 -AF(I,J,K)-AB(I,J,K)	00349700
300 CONTINUE	00349800
	00349900
C *** SOLUTION OF FINITE DIFFERENCE EQUATION	00350000
	00350100
CALL TRID (2,2,2,NI,NJ,NK,PP)	00350200
	00350300
C *** THIS IS FOR CHECKING	00350400
	00350500
	00350600
DO 161 I=1,NIP1	00350700
C WRITE (6,*) :	00350800
949 FORMAT (' AW ')	00350900
C WRITE (6,949)	00351000
C WRITE (6,999) ((AW(I,J,K),K=1,NKP1),J=1,NJP1)	00351100
161 CONTINUE	00351200

C	DO 160 I=1,NIP1	00351300
C	WRITE (6,*) I	00351400
948	FORMAT (' AE '	00351500
C	WRITE (6,948)	00351600
C	WRITE (6,999) ((AE(I,J,K),K=1,NKP1),J=1,NJP1)	00351700
160	CONTINUE	00351800
C	DO 170 I=1,NIP1	00351900
C	WRITE (6,*) I	00352000
958	FORMAT (' AB '	00352100
C	WRITE (6,958)	00352200
C	WRITE (6,999) ((AB(I,J,K),K=1,NKP1),J=1,NJP1)	00352300
170	CONTINUE	00352400
C	DO 180 I=1,NIP1	00352500
C	WRITE (6,*) I	00352600
968	FORMAT (' AF '	00352700
C	WRITE (6,968)	00352800
C	WRITE (6,999) ((AF(I,J,K),K=1,NKP1),J=1,NJP1)	00352900
180	CONTINUE	00353000
C	WRITE (6,999) ((SU(I,J,K),K=1,NKP1),I=1,NIP1)	00353100
C	DO 190 I=1,NIP1	00353200
C	WRITE (6,*) I	00353300
978	FORMAT (' SU '	00353400
C	WRITE (6,978)	00353500
C	WRITE (6,999) ((SU(I,J,K),K=1,NKP1),J=1,NJP1)	00353600
190	CONTINUE	00353700
C	DO 191 I=1,NIP1	00353800
C	WRITE (6,*) I	00353900
C	WRITE (6,988)	00354000
988	FORMAT (' PP '	00354100
C	WRITE (6,999) ((PP(I,J,K),J=1,NJP1),K=7,7)	00354200
191	CONTINUE	00354300
999	FORMAT (12E10.3)	00354400
		00354500
		00354600
		00354700
C ***	CORRECT VELOCITIES AND PRESSURE	00354800
C		00354900
C ***	CORRECTION FOR VELOCITY U	00355000
		00355100
	DO 600 I=2,NI	00355200
	IM1=I-1	00355300
	IF (I.EQ.2) IM1=NI	00355400
	DO 600 J=2,NJ	00355500
	DO 600 K=2,NK	00355600
	U(I,J,K)=U(I,J,K)+DU(I,J,K)*(PP(IM1,J,K)-PP(I,J,K))	00355700
600	CONTINUE	00355800
		00355900
C ***	CORRECTION FOR VELOCITY V	00356000
		00356100
	DO 603 J=3,NJ	00356200
	JM1=J-1	00356300
	DO 603 K=2,NK	00356400
	DO 603 I=2,NI	00356500
	V(I,J,K)=V(I,J,K)+DV(I,J,K)*(PP(I,JM1,K)-PP(I,J,K))	00356600
603	CONTINUE	00356700
		00356800
C ***	CORRECTION OF VELOCITY W	00356900
		00357000
	DO 604 K=3,NK	00357100
	KM1=K-1	00357200
	DO 604 I=2,NI	00357300
	DO 604 J=2,NJ	00357400
	W(I,J,K)=W(I,J,K)+DW(I,J,K)*(PP(I,J,KM1)-PP(I,J,K))	00357500
604	CONTINUE	00357600
		00357700
		00357800
C ***	CORRECTION FOR PRESSURE P	00357900
		00358000

DO 606 J=2,NJ	00358100
DO 606 I=1,NIP1	00358200
DO 606 K=1,NK	00358300
P(I,J,K)=P(I,J,K)+PP(I,J,K)	00358400
PP(I,J,K)=0.	00358500
606 CONTINUE	00358600
C *** THIS IS FOR R=0.0 CASE	00358700
DO 75 I=1,NIP1	00358800
DO 75 K=1,NKP1	00358900
C U(I,1,K)=U(I,2,K)	00359000
C W(I,1,K)=W(I,2,K)	00359100
C V(I,2,K)=V(I,3,K)	00359200
75 CONTINUE	00359300
	00359400
	00359500
	00359600
	00359700
C *** MODIFICATION FOR R=0.0	00359800
C	00359900
DO 55 K=2,NK	00360000
VY=0.0	00360100
VX=0.0	00360200
VZ=0.0	00360300
DO 50 I=2,NI	00360400
VY=VY+U(I,2,K)*COS(XS(I))	00360500
VX=VX-U(I,2,K)*SIN(XS(I))	00360600
50 CONTINUE	00360700
	00360800
DO 51 I=2,NI	00360900
VY=VY+V(I,3,K)*SIN(XC(I))	00361000
VX=VX+V(I,3,K)*COS(XC(I))	00361100
VZ=VZ+W(I,2,K)	00361200
51 CONTINUE	00361300
	00361400
	00361500
C *** FIND THE VELOCITIES AT R=0.0	00361600
DO 52 I=1,NIP1	00361700
U(I,1,K)=(-VX*SIN(XS(I))+VY*COS(XS(I)))/NIM1	00361800
V(I,2,K)=(VX*COS(XC(I))+VY*SIN(XC(I)))/NIM1	00361900
W(I,1,K)=VZ/NIM1	00362000
52 CONTINUE	00362100
55 CONTINUE	00362200
	00362300
	00362400
	00362500
	00362600
C *** THIS IS FOR THE CYLINDER ONLY (CYLIC CONDITION)	00362700
DO 76 J=1,NJP1	00362800
DO 76 K=1,NKP1	00362900
U(1,J,K)=U(NI,J,K)	00363000
U(NIP1,J,K)=U(2,J,K)	00363100
V(1,J,K)=V(NI,J,K)	00363200
V(NIP1,J,K)=V(2,J,K)	00363300
W(1,J,K)=W(NI,J,K)	00363400
W(NIP1,J,K)=W(2,J,K)	00363500
76 CONTINUE	00363600
	00363700
	00363800
C *** THIS FOR SPHERE ONLY	00363900
DO 77 I=1,NIP1	00364000
DO 77 J=1,NJP1	00364100
U(I,J,1)=U(I,J,2)	00364200
V(I,J,1)=V(I,J,2)	00364300
W(I,J,2)=W(I,J,3)	00364400
U(I,J,NKP1)=U(I,J,NK)	00364500
V(I,J,NKP1)=V(I,J,NK)	00364600
W(I,J,NKP1)=W(I,J,NK)	00364700
	00364800

```

77 CONTINUE
IF (NCHIP.EQ.0) GOTO 116
C *****
C *****
C *** RESET THE VELOCITY INSIDE OF DECK

DO 120 N=1,NCHIP
  IB=ICHPB(N)
  IE=IB+NCHPI(N)-1
  JB=JCHPB(N)
  JE=JB+NCHPJ(N)-1
  KB=KCHPB(N)
  KE=KB+NCHPK(N)-1

DO 109 I=IB,IE
DO 109 J=JB,JE-1
DO 109 K=KB,KE-1
  U(I,J,K)=0.0
109 CONTINUE

DO 118 I=IB,IE-1
DO 118 J=JB,JE
DO 118 K=KB,KE-1
  V(I,J,K)=0.0
118 CONTINUE

DO 119 I=IB,IE-1
DO 119 J=JB,JE-1
DO 119 K=KB,KE
  W(I,J,K)=WFAN(N)
119 CONTINUE
120 CONTINUE
116 CONTINUE
C *****
C *****
C *** RECALCULATE THE ERROR SOURCE AFTER CORRECTIONS OF U, V, W

SORSUM=0.
RESORM(ITER)=0.
DO 700 J=2,NJ
  JP1=J-1
  JX1=J-1
  DO 700 I=2,NI
    IP1=I-1
    IX1=I-1
    DO 700 K=2,NK
      KP1=K-1
      KM1=K-1

C CENTRAL LENGTH OF THE SCALAR CONTROL VOLUME

DXP1=XL(IP1,J,K,0,0)
DXI=XL(I,J,K,0,0)
DXM1=XL(IM1,J,K,0,0)

DYP1=YL(I,JP1,K,0,0)
DYJ=YL(I,J,K,0,0)
DYM1=YL(I,JM1,K,0,0)

DZP1=ZL(I,J,KP1,0,0)
DZK=ZL(I,J,K,K,0,0)
DZM1=ZL(I,J,KM1,0,0)

```

C *** SURFACE LENGTH OF THE CONTROL VOLUME

DXN=XL(I,JP1,K,0,2)
DXS=XL(I,J,K,0,2)
DXF=XL(I,J,KP1,0,3)
DXB=XL(I,J,K,0,3)

DYF=YL(I,J,KP1,0,3)
DYB=YL(I,J,K,0,3)
DYE=YL(IP1,J,K,0,1)
DYW=YL(I,J,K,0,1)

DZE=ZL(IP1,J,K,0,1)
DZW=ZL(I,J,K,0,1)
DZN=ZL(I,JP1,K,0,2)
DZS=ZL(I,J,K,0,2)

C *** DEFINE AREA OF THE CONTROL VOLUME

DXYF=DXF*DYF
DXYB=DXB*DYB
DYZE=DYE*DZE
DYZW=DYW*DZW
DZXN=DZN*DXN
DZXS=DZS*DXS

VOL=DXI*DYJ*DZK
VOLDT=VOL/DTIME

RN=(R(I,J,K)*DYP1+R(I,JP1,K)*DYJ)/(DYP1+DYJ)
RS=(R(I,J,K)*DYM1+R(I,JM1,K)*DYJ)/(DYM1+DYJ)
RE=(R(I,J,K)*DXP1+R(IP1,J,K)*DXI)/(DXP1+DXI)
RW=(R(I,J,K)*DXM1+R(IM1,J,K)*DXI)/(DXM1+DXI)
RF=(R(I,J,K)*DZP1+R(I,J,KP1)*DZK)/(DZP1+DZK)
RB=(R(I,J,K)*DZM1+R(I,J,KM1)*DZK)/(DZM1+DZK)

CN=RN*V(I,JP1,K)*DZXN
CS=RS*V(I,J,K)*DZXS
CE=RE*U(IP1,J,K)*DYZE
CW=RW*U(I,J,K)*DYZW
CF=RF*W(I,J,KP1)*DXYF
CB=RB*W(I,J,K)*DXYB

C SMP(I,J,K)=-CE-CW-CN-CS-CF-CB
SMP(I,J,K)=-(R(I,J,K)-ROD(I,J,K))*VOL/DTIME-CE-CW-CN-CS-CF-CB

C *** SORSUM IS ACTUAL MASS INCREASE OR DECREASE FROM CONTINUITY
C EQUATION , THIS WILL COMPARE TO SOURCE

SORSUM=SORSUM+SMP(I,J,K)

C *** RESORM IS SUM OF THE ABSOLUTE VALUE OF SMP(I,J,K)

RESORM(ITER)=RESORM(ITER)+ABS(SMP(I,J,K))
700 CONTINUE
RETURN
END

C SUBROUTINE TRID(IST,JST,KST,ISP,JSP,KSP,PHI)

C
COMMON/BL7/N1,NIP1,NIM1,NJ,NJP1,NJM1,NK,NKP1,NKM1

00371400
00371500
00371600
00371700
00371800
00371900
00372000
00372100
00372200
00372300
00372400
00372500
00372600
00372700
00372800
00372900
00373000
00373100
00373200
00373300
00373400
00373500
00373600
00373700
00373800
00373900
00374000
00374100
00374200
00374300
00374400
00374500
00374600
00374700
00374800
00374900
00375000
00375100
00375200
00375300
00375400
00375500
00375600
00375700
00375800
00375900
00376000
00376100
00376200
00376300
00376400
00376500
00376600
00376700
00376800
00376900
00377000
00377100
00377200
00377300
00377400
00377500
00377600
00377700
00377800
00377900
00378000
00378100

&	,NIP2,NJP2,NKP2,NA,NAP1,NAM1,NB,NBP1,NBM1,KRUN,NCHIP,NJRA,NWRP	00378200
	COMMON/BL36/AP(22,16,32),AE(22,16,32),AW(22,16,32),AN(22,16,32),	00378300
&	AS(22,16,32),AF(22,16,32),AB(22,16,32),	00378400
&	SP(22,16,32),SU(22,16,32),RI(22,16,32)	00378500
	DIMENSION A(99),B(99),C(99),PHI(22,16,32)	00378600
		00378700
C	GOTO 405	00378800
	ISTM1=IST-1	00378900
	A(ISTM1)=0.	00379000
	C(ISTM1)=0.	00379100
	DO 100 J=JST,JSP	00379200
	DO 100 K=KST,KSP	00379300
	DO 101 I=IST,ISP	00379400
	A(I)=AE(I,J,K)	00379500
	B(I)=AW(I,J,K)	00379600
	C(I)=AN(I,J,K)*PHI(I,J+1,K)+AS(I,J,K)*PHI(I,J-1,K)	00379700
&	-AF(I,J,K)*PHI(I,J,K+1)+AB(I,J,K)*PHI(I,J,K-1)+SU(I,J,K)	00379800
	TERM=1./(AP(I,J,K)-B(I)*A(I-1))	00379900
	IF (ABS(A(I)).LE.1.0E-10) A(I)=0.0	00380001
	IF (ABS(B(I)).LE.1.0E-10) B(I)=0.0	00380002
	IF (ABS(C(I)).LE.1.0E-10) C(I)=0.0	00380003
	IF (ABS(TERM).LE.1.0E-10) TERM=0.0	00380010
	A(I)=A(I)*TERM	00380020
	C(I)=(C(I)+B(I)*C(I-1))*TERM	00380100
101	CONTINUE	00380500
	PHI(ISP,J,K)=C(ISP)	00380600
	ISTA=IST+1	00380700
	DO 102 II=ISTA,ISP	00380800
	I=IST+ISP-II	00380900
	IP1=I-1	00381000
	PHI(I,J,K)=A(I)*PHI(IP1,J,K)+C(I)	00381100
102	CONTINUE	00381200
100	CONTINUE	00381300
		00381400
	DO 2000 J=JST,JSP	00381500
	DO 2000 K=KST,KSP	00381600
	PHI(IST-1,J,K)=PHI(IST,J,K)	00381700
	PHI(ISP-1,J,K)=PHI(IST,J,K)	00381800
2000	CONTINUE	00381900
		00382000
		00382100
	JSTM1=JST-1	00382200
	A(JSTM1)=0.	00382300
	C(JSTM1)=0.	00382400
	DO 200 K=KST,KSP	00382500
	DO 200 I=IST,ISP	00382600
	DO 201 J=JST,JSP	00382700
	A(J)=AN(I,J,K)	00382800
	B(J)=AS(I,J,K)	00382900
	C(J)=AE(I,J,K)*PHI(I-1,J,K)+AW(I,J,K)*PHI(I-1,J,K)	00383000
&	-AF(I,J,K)*PHI(I,J,K+1)+AB(I,J,K)*PHI(I,J,K-1)+SU(I,J,K)	00383100
	TERM=1./(AP(I,J,K)-B(J)*A(J-1))	00383200
	IF (ABS(A(J)).LE.1.0E-10) A(J)=0.0	00383210
	IF (ABS(B(J)).LE.1.0E-10) B(J)=0.0	00383220
	IF (ABS(C(J)).LE.1.0E-10) C(J)=0.0	00383230
	IF (ABS(TERM).LE.1.0E-10) TERM=0.0	00383240
	A(J)=A(J)*TERM	00383300
	C(J)=(C(J)+B(J)*C(J-1))*TERM	00383400
201	CONTINUE	00383800
	PHI(I,JSP,K)=C(JSP)	00383900
	JSTA=JST-1	00384000
	DO 202 JJ=JSTA,JSP	00384100
	J=JST+JSP-JJ	00384200
	JP1=J-1	00384300
	PHI(I,J,K)=A(J)*PHI(I,JP1,K)+C(J)	00384400
202	CONTINUE	00384500
200	CONTINUE	00384600
		00384700

DO 2001 J=JST,JSP	00384800
DO 2001 K=KST,KSP	00384900
PHI(IST-1,J,K)=PHI(ISP,J,K)	00385000
PHI(ISP+1,J,K)=PHI(IST,J,K)	00385100
2001 CONTINUE	00385200
	00385300
	00385400
KSTM1=KST-1	00385500
A(KSTM1)=0.	00385600
C(KSTM1)=0.	00385700
DO 300 I=IST,ISP	00385800
DO 300 J=JST,JSP	00385900
DO 301 K=KST,KSP	00386000
A(K)=AF(I,J,K)	00386100
B(K)=AB(I,J,K)	00386200
C(K)=AE(I,J,K)*PHI(I+1,J,K)+AW(I,J,K)*PHI(I-1,J,K)	00386300
6 -AN(I,J,K)*PHI(I,J+1,K)+AS(I,J,K)*PHI(I,J-1,K)+SU(I,J,K)	00386400
TERM=1./(AP(I,J,K)-B(K)*A(K-1))	00386500
IF (ABS(A(K)).LE.1.0E-10) A(K)=0.0	00386510
IF (ABS(B(K)).LE.1.0E-10) B(K)=0.0	00386520
IF (ABS(C(K)).LE.1.0E-10) C(K)=0.0	00386530
IF (ABS(TERM).LE.1.0E-10) TERM=0.0	00386540
A(K)=A(K)*TERM	00386600
C(K)=(C(K)+B(K)*C(K-1))*TERM	00386700
301 CONTINUE	00387100
PHI(I,J,KSP)=C(KSP)	00387200
KSTA=KST+1	00387300
DO 302 KK=KSTA,KSP	00387400
K=KST+KSP-KK	00387500
KP1=K+1	00387600
PHI(I,J,K)=A(K)*PHI(I,J,KP1)+C(K)	00387700
302 CONTINUE	00387800
300 CONTINUE	00387900
	00388000
	00388100
DO 2002 J=JST,JSP	00388200
DO 2002 K=KST,KSP	00388300
PHI(IST-1,J,K)=PHI(ISP,J,K)	00388400
PHI(ISP+1,J,K)=PHI(IST,J,K)	00388500
2002 CONTINUE	00388600
	00388700
	00388800
GOTO 700	00388900
	00389000
4405 CONTINUE	00389100
405 KSP1=KSP-1	00389200
B(KSP1)=0.	00389300
C(KSP1)=0.	00389400
DO 600 II=IST,ISP	00389500
I=IST+ISP-II	00389600
DO 600 JJ=JST,JSP	00389700
J=JST+JSP-JJ	00389800
DO 601 KK=KST,KSP	00389900
K=KSP+KST-KK	00390000
KP1=K-1	00390100
A(K)=AF(I,J,K)	00390200
B(K)=AB(I,J,K)	00390300
C(K)=AE(I,J,K)*PHI(I+1,J,K)+AW(I,J,K)*PHI(I-1,J,K)+AN(I,J,K)*	00390400
6 PHI(I,J+1,K)+AS(I,J,K)*PHI(I,J-1,K)+SU(I,J,K)	00390500
TERM=1./(AP(I,J,K)-A(K)*B(K+1))	00390600
B(K)=B(K)*TERM	00390700
C(K)=(C(K)+A(K)*C(K+1))*TERM	00390800
IF (ABS(A(K)).LE.1.0E-10) A(K)=0.0	00390900
IF (ABS(B(K)).LE.1.0E-10) B(K)=0.0	00391000
IF (ABS(C(K)).LE.1.0E-10) C(K)=0.0	00391100
601 CONTINUE	00391200
PHI(I,J,KST)=C(KST)	00391300
KSTP1=KST+1	00391400
DO 602 K=KSTP1,KSP	

	PHI(I,J,K)=B(K)*PHI(I,J,K-1)+C(K)	00391500
602	CONTINUE	00391600
600	CONTINUE	00391700
		00391800
	DO 2003 J=JST,JSP	00391900
	DO 2003 K=KST,KSP	00392000
	PHI(IST-1,J,K)=PHI(IST,J,K)	00392100
	PHI(IST+1,J,K)=PHI(IST,J,K)	00392200
2003	CONTINUE	00392300
		00392400
	JSP1=JSP+1	00392500
	B(JSP1)=0.	00392600
	C(JSP1)=0.	00392700
	DO 500 KK=KST,KSP	00392800
	K=KST+KSP-KK	00392900
	DO 500 II=IST,ISP	00393000
	I=IST+ISP-II	00393100
	DO 501 JJ=JST,JSP	00393200
	J=JSP+JST-JJ	00393300
	JPI=J+1	00393400
	A(J)=AN(I,J,K)	00393500
	B(J)=AS(I,J,K)	00393600
	C(J)=AE(I,J,K)*PHI(I+1,J,K)+AW(I,J,K)*PHI(I-1,J,K)+AF(I,J,K)*	00393700
	PHI(I,J,K+1)+AB(I,J,K)*PHI(I,J,K-1)+SU(I,J,K)	00393800
	TERM=1./(AP(I,J,K)-A(J)*B(J-1))	00393900
	B(J)=B(J)*TERM	00394000
	C(J)=(C(J)+A(J)*C(J+1))*TERM	00394100
	IF (ABS(A(J)).LE.1.0E-10) A(J)=0.0	00394200
	IF (ABS(B(J)).LE.1.0E-10) B(J)=0.0	00394300
	IF (ABS(C(J)).LE.1.0E-10) C(J)=0.0	00394400
501	CONTINUE	00394500
	PHI(I,JST,K)=C(JST)	00394600
	JSTP1=JST+1	00394700
	DO 502 J=JSTP1,JSP	00394800
	PHI(I,J,K)=B(J)*PHI(I,J-1,K)+C(J)	00394900
502	CONTINUE	00395000
500	CONTINUE	00395100
		00395200
		00395300
	DO 2004 J=JST,JSP	00395400
	DO 2004 K=KST,KSP	00395500
	PHI(IST-1,J,K)=PHI(IST,J,K)	00395600
	PHI(IST+1,J,K)=PHI(IST,J,K)	00395700
2004	CONTINUE	00395800
		00395900
		00396000
	ISP1=ISP-1	00396100
	B(ISP1)=0.	00396200
	C(ISP1)=0.	00396300
	DO 400 JJ=JST,JSP	00396400
	J=JST+JSP-JJ	00396500
	DO 400 KK=KST,KSP	00396600
	K=KST+KSP-KK	00396700
	DO 400 II=IST,ISP	00396800
	I=ISP+IST-II	00396900
	JPI=I-1	00397000
	A(I)=AE(I,J,K)	00397100
	B(I)=AW(I,J,K)	00397200
	C(I)=AN(I,J,K)*PHI(I,J+1,K)+AS(I,J,K)*PHI(I,J-1,K)+AF(I,J,K)*	00397300
	PHI(I,J,K+1)+AB(I,J,K)*PHI(I,J,K-1)+SU(I,J,K)	00397400
	TERM=1./(AP(I,J,K)-A(I)*B(I-1))	00397500
	B(I)=B(I)*TERM	00397600
	C(I)=(C(I)+A(I)*C(I+1))*TERM	00397700
	IF (ABS(A(I)).LE.1.0E-10) A(I)=0.0	00397800
	IF (ABS(B(I)).LE.1.0E-10) B(I)=0.0	00397900
	IF (ABS(C(I)).LE.1.0E-10) C(I)=0.0	00398000
401	CONTINUE	00398100
	PHI(IST,J,K)=C(IST)	00398200

ISTP1=IST+1	00398300
DO 402 I=ISTP1,ISP	00398400
PHI(I,J,K)=B(I)*PHI(I-1,J,K)+C(I)	00398500
402 CONTINUE	00398600
400 CONTINUE	00398700
	00398800
DO 2005 J=JST,JSP	00398900
DO 2005 K=KST,KSP	00399000
PHI(IST-1,J,K)=PHI(IST,J,K)	00399100
PHI(IST+1,J,K)=PHI(IST,J,K)	00399200
2005 CONTINUE	00399300
	00399400
	00399500
700 CONTINUE	00399600
RETURN	00399700
END	00399800
	00399900
C *****	00400000
BLOCK DATA	00400100
C *****	00400200
	00400300
COMMON/BL7/NI,NIP1,NIM1,NJ,NJP1,NJM1,NK,NKP1,NKM1	00400400
& ,NIP2,NJP2,NKP2,NA,NAP1,NAM1,NB,NBP1,NBM1,KRUN,NCHIP,NJRA,NWRP	00400500
COMMON/BL12/ NWRITE,NTAPE,NTMAX0,NTREAL,TIME,SORSUM,ITER	00400600
COMMON/BL14/HCOEF,TINF,CNT,ABTURB,BTURB,VISL,VISMAX,QCORRT,PM1,PM200400700	00400700
COMMON/BL16/ CONST1,CONST2,CONST3,CONST4,CONST6,NT,UO,H,UGRT,BUOY,00400800	00400800
& CPO,PRT,CONDO,VISO,RHOO,HR,TR,TA,DTEMP,TWRITE,TTAPE,TMAX,GC,RAIR00400900	00400900
DATA NIP2,NIP1,NI,NIM1/23,22,21,20/	00401000
DATA NJP2,NJP1,NJ,NJM1/17,16,15,14/	00401100
DATA NKP2,NKP1,NK,NKM1/33,32,31,30/	00401200
DATA NAP1,NA,NAM1,NBP1,NB,NBM1/9,8,7,27,26,25/	00401300
DATA UO,TA,PRT,RHOO,CPO,VISO,NTMAX0/	00401400
& 1.0,555.86,1.0,0.0714,0.24,1.56E-4,0/	00401500
DATA TINF,CNT,ABTURB,BTURB/1.0,0.2,2.0,1.0/	00401600
DATA GC,RAIR/32.17,53.34/	00401700
DATA QCORRT,PM1/1.0,0.9/	00401800
END	00401900
	00402000
	00402100
	00402200
C *****	00402300
SUBROUTINE GRID	00402400
C *****	00402500
COMMON/R4/XC(93),YC(93),ZC(93),XS(93),YS(93),ZS(93),	00402600
& DXXC(93),DYXC(93),DZZC(93),DXXS(93),DYYS(93),DZZS(93)	00402700
COMMON/BL1/ DX,DY,DZ,VOL,DTIME,VOLDT,THOT,TCOOL,PI,Q,QR	00402800
COMMON/BL7/NI,NIP1,NIM1,NJ,NJP1,NJM1,NK,NKP1,NKM1	00402900
& ,NIP2,NJP2,NKP2,NA,NAP1,NAM1,NB,NBP1,NBM1,KRUN,NCHIP,NJRA,NWRP	00403000
	00403100
C *** REGENERATION OF GRID	00403200
	00403300
PI=4.*ATAN(1.)	00403400
DX=1.0/FLOAT(NIM1)	00403500
C DY=1./FLOAT(NJM1-2)	00403600
DY=1./FLOAT(NJM1-1)	00403700
DZ=PI/FLOAT(NKM1-NB+NA-2)	00403800
	00403900
	00404000
DO 19 I=1,NIP2	00404100
XS(I)=(I-2)*DX*2.0*PI	00404200
19 CONTINUE	00404300
	00404400
C XS(1)=-DX*2.0*PI	00404500
C XS(2)=0.0	00404600
C XS(3)=0.0*2.0*PI	00404700
C DO 19 I=4,13	00404800
C XS(I)=(I-3)*DX*2.0*PI	00404900
C 19 CONTINUE	00405000

C		00405100
C	XS(14)=XS(13)	00405200
C	XS(13)=XS(14)-0.01*2.0*PI	00405300
C	DO 18 I=15,NIP1	00405400
C	XS(I)=XS(14)+(I-14)*DX*2.0*PI	00405500
C	18 CONTINUE	00405600
C	XS(NIP2)=XS(NIP1)+XS(3)	00405700
		00405800
		00405900
	YS(1)=0.000	00406000
	YS(2)=0.025	00406100
C	YS(3)=0.05	00406200
	DO 3 J=3,NJ	00406300
	YS(J)=(J-2)*DY	00406400
3	CONTINUE	00406500
	YS(NJP1)=YS(NJ)	00406600
	YS(NJ)=YS(NJP1)-3./8./12./9.6	00406700
	YS(NJP2)=YS(NJP1)+3./8./12./9.6	00406800
		00406900
CC	DO 3 J=4,NJP2	00407000
CC	YS(J)=(J-3)*DY	00407100
CC 3	CONTINUE	00407200
	DO 4 I=1,NIP1	00407300
	IP1=I+1	00407400
	DXXC(I)=XS(IP1)-XS(I)	00407500
4	CONTINUE	00407600
		00407700
	DXXC(NIP2)=DXXC(NIP1)	00407800
	DO 5 I=2,NIP2	00407900
	IM1=I-1	00408000
	DXXS(I)=.5*(DXXC(I)+DXXC(IM1))	00408100
5	CONTINUE	00408200
	DXXS(1)=DXXS(2)	00408300
		00408400
	DO 7 J=1,NJP1	00408500
	JP1=J+1	00408600
	DYYC(J)=YS(JP1)-YS(J)	00408700
7	CONTINUE	00408800
		00408900
	DYYC(NJP2)=DYYC(NJP1)	00409000
	DO 8 J=2,NJP2	00409100
	JM1=J-1	00409200
	DYYS(J)=.5*(DYYC(J)+DYYC(JM1))	00409300
8	CONTINUE	00409400
	DYYS(1)=DYYS(2)	00409500
		00409600
	DO 20 I=1,NIP2	00409700
	XC(I)=XS(I)+DXXC(I)/2.0	00409800
20	CONTINUE	00409900
		00410000
	DO 21 J=1,NJP2	00410100
	YC(J)=YS(J)+DYYC(J)/2.0	00410200
21	CONTINUE	00410300
		00410400
		00410500
	DO 9 K=4,NA	00410600
	ZS(K)=(K-3)*DZ	00410700
9	CONTINUE	00410800
		00410900
	DO 30 K=NBPI,NK	00411000
	ZS(K)=ZS(NA)+(K-NB)*DZ	00411100
30	CONTINUE	00411200
		00411300
	DO 31 K=NAPI,NB	00411400
	ZS(K)=PI/2.	00411500
31	CONTINUE	00411600
		00411700
	ZS(1)=0.0	00411800

	ZS(2)=0.05	00411900
	ZS(3)=0.10	00412000
C	ZS(NKP1)=ZS(NKM1)	00412100
C	ZS(NK)=ZS(NKP1)-0.05	00412200
C	ZS(NKM1)=ZS(NKP1)-0.10	00412300
C	ZS(NKP2)=ZS(NKP1)+0.05	00412400
		00412500
	ZS(NKP2)=ZS(NK)	00412600
	ZS(NKP1)=ZS(NKP2)-0.05	00412700
	ZS(NK)=ZS(NKP2)-0.10	00412800
		00412900
		00413000
	DO 10 K=1,NKP1	00413100
	IF (K.GE.NA.AND.K.LT.NB) GOTO 10	00413200
	KP1=K+1	00413300
	DZZC(K)=ZS(KP1)-ZS(K)	00413400
10	CONTINUE	00413500
		00413600
	DO 32 K=NA,NBM1	00413700
	DZZC(K)=2.854/(NB-NA)	00413800
32	CONTINUE	00413900
		00414000
	DZZC(NKP2)=DZZC(NKP1)	00414100
		00414200
	DO 11 K=2,NKP2	00414300
C	IF (K.EQ.NA.OR.K.EQ.NB) GOTO 11	00414400
	KM1=K-1	00414500
	DZZS(K)=.5*(DZZC(K)+DZZC(KM1))	00414600
11	CONTINUE	00414700
		00414800
	DZZS(1)=DZZS(2)	00414900
	DO 22 K=1,NKP2	00415000
	IF (K.GE.NA.AND.K.LT.NB) GOTO 22	00415100
	ZC(K)=ZS(K)+DZZC(K)/2.0	00415200
22	CONTINUE	00415300
		00415400
	DO 33 K=NA,NBM1	00415500
	ZC(K)=PI/2.	00415600
33	CONTINUE	00415700
		00415800
	IF (YS(1).LT.0.0) YS(1)=0.0	00415900
	IF (YC(1).LT.0.0) YC(1)=0.0	00416000
	PRINT *	00416100
	PRINT 'INPUT COORDINATE OF THE TANK IN THE ORDER OF '	00416200
	PRINT 'XS YS ZS XC YC',	00416300
	6, 'ZC DXXS DYYS DZZS DXXC	00416400
	6, 'DYXC DZZC'	00416500
	DO 12 I=1,NKP2	00416600
C	WRITE(6,102) I,XS(I),YS(I),ZS(I),XC(I),YC(I),ZC(I),	00416700
C	6, DXXS(I),DYYS(I),DZZS(I),DXXC(I),DYXC(I),DZZC(I)	00416800
C 102	FORMAT(2X,14,12(2X,F8.5))	00416900
12	CONTINUE	00417000
		00417100
	RETURN	00417200
	END	00417300
		00417400
		00417500
		00417600
C	*****	00417700
	FUNCTION XL(I,J,K,M,N)	00417800
C	*****	00417900
C	*****	00418000
C	WHEN M OR N = 1 THEN SHIFT CELL IN THE NEG X DIRECTION ONE*	00418100
C	HALF CELL (STAGGERED CELL)	00418200
C	WHEN M OR N = 2 THEN SHIFT CELL IN THE NEG Y DIRECTION ONE*	00418300
C	HALF CELL (STAGGERED CELL)	00418400
C	WHEN M OR N = 3 THEN SHIFT CELL IN THE NEG Z DIRECTION ONE*	00418500
C	HALF CELL (STAGGERED CELL)	00418600

C	WHEN X = N = 1 THEN SHIFT CELL IN THE NEG X DIRECTION ONE*	00418700
C	WHOLE CELL	00418800
C	WHEN X = N = 2 THEN SHIFT CELL IN THE NEG Y DIRECTION ONE*	00418900
C	WHOLE CELL	00419000
C	WHEN X = N = 3 THEN SHIFT CELL IN THE NEG Z DIRECTION ONE*	00419100
C	WHOLE CELL	00419200
C	*****	00419300
	COMMON/R4/XC(93),YC(93),ZC(93),XS(93),YS(93),ZS(93),	00419400
	& DXXC(93),DYXC(93),DZZC(93),DXXS(93),DYYS(93),DZZS(93)	00419500
	X1=XC(I)	00419600
	X2=YC(J)	00419700
	X3=ZC(K)	00419800
	DXL=DXXC(I)	00419900
	IF(M.EQ.N) GOTO 100	00420000
		00420100
	IF(M.EQ.1.OR.N.EQ.1) X1=XS(I)	00420200
	IF(M.EQ.1.OR.N.EQ.1) DXL=DXXS(I)	00420300
	IF(M.EQ.2.OR.N.EQ.2) X2=YS(J)	00420400
	IF(M.EQ.3.OR.N.EQ.3) X3=ZS(K)	00420500
	GOTO 1000	00420600
100	IF(M.EQ.1) X1=XC(I-1)	00420700
	IF(M.EQ.1) DXL=DXXC(I-1)	00420800
	IF(M.EQ.2) X2=YC(J-1)	00420900
	IF(M.EQ.3) X3=ZC(K-1)	00421000
1000	CONTINUE	00421100
	XL=X2*SIN(X3)*DXL	00421200
	RETURN	00421300
	END	00421400
		00421500
		00421600
		00421700
C	*****	00421800
	FUNCTION YL(I,J,K,M,N)	00421900
C	*****	00422000
C	*****	00422100
C	WHEN X OR N = 1 THEN SHIFT CELL IN THE NEG X DIRECTION ONE*	00422200
C	HALF CELL (STAGGERED CELL)	00422300
C	WHEN X OR N = 2 THEN SHIFT CELL IN THE NEG Y DIRECTION ONE*	00422400
C	HALF CELL (STAGGERED CELL)	00422500
C	WHEN X OR N = 3 THEN SHIFT CELL IN THE NEG Z DIRECTION ONE*	00422600
C	HALF CELL (STAGGERED CELL)	00422700
C	WHEN X = N = 1 THEN SHIFT CELL IN THE NEG X DIRECTION ONE*	00422800
C	WHOLE CELL	00422900
C	WHEN X = N = 2 THEN SHIFT CELL IN THE NEG Y DIRECTION ONE*	00423000
C	WHOLE CELL	00423100
C	WHEN X = N = 3 THEN SHIFT CELL IN THE NEG Z DIRECTION ONE*	00423200
C	WHOLE CELL	00423300
C	*****	00423400
	COMMON/R4/XC(93),YC(93),ZC(93),XS(93),YS(93),ZS(93),	00423500
	& DXXC(93),DYXC(93),DZZC(93),DXXS(93),DYYS(93),DZZS(93)	00423600
	X1=XC(I)	00423700
	X2=YC(J)	00423800
	X3=ZC(K)	00423900
	DYL=DYXC(J)	00424000
	IF(M.EQ.N) GOTO 100	00424100
		00424200
	IF(M.EQ.2.OR.N.EQ.2) X2=YS(J)	00424300
	IF(M.EQ.2.OR.N.EQ.2) DYL=DYYS(J)	00424400
	IF(M.EQ.1.OR.N.EQ.1) X1=XS(I)	00424500
	IF(M.EQ.3.OR.N.EQ.3) X3=ZS(K)	00424600
	GOTO 1000	00424700
100	IF(M.EQ.2) X2=YC(J-1)	00424800
	IF(M.EQ.2) DYL=DYXC(J-1)	00424900
	IF(M.EQ.1) X1=XC(I-1)	00425000
	IF(M.EQ.3) X3=ZC(K-1)	00425100
1000	CONTINUE	00425200
	YL=1.00*DYL	00425300
	RETURN	00425400

END	00425500
	00425600
	00425700
C *****	00425800
FUNCTION ZL(I,J,K,M,N)	00425900
C *****	00426000
C*****	00426100
C WHEN M OR N = 1 THEN SHIFT CELL IN THE NEG X DIRECTION ONE*	00426200
C HALF CELL (STAGGERED CELL) *	00426300
C WHEN M OR N = 2 THEN SHIFT CELL IN THE NEG Y DIRECTION ONE*	00426400
C HALF CELL (STAGGERED CELL) *	00426500
C WHEN M OR N = 3 THEN SHIFT CELL IN THE NEG Z DIRECTION ONE*	00426600
C HALF CELL (STAGGERED CELL) *	00426700
C WHEN M = N = 1 THEN SHIFT CELL IN THE NEG X DIRECTION ONE*	00426800
C WHOLE CELL *	00426900
C WHEN M = N = 2 THEN SHIFT CELL IN THE NEG Y DIRECTION ONE*	00427000
C WHOLE CELL *	00427100
C WHEN M = N = 3 THEN SHIFT CELL IN THE NEG Z DIRECTION ONE*	00427200
C WHOLE CELL *	00427300
C*****	00427400
COMMON/R4/XC(93),YC(93),ZC(93),XS(93),YS(93),ZS(93),	00427500
& DXXC(93),DYXC(93),DZZC(93),DXXS(93),DYYS(93),DZZS(93)	00427600
COMMON/BL7/NI,NIP1,NIM1,NJ,NJP1,NJM1,NK,NKP1,NKM1	00427700
& ,NIP2,NJP2,NKP2,NA,NAP1,NAM1,NB,NBP1,NBM1,KRUN,NCHIP,NJRA,NWRP	00427800
X1=XC(I)	00427900
X2=YC(J)	00428000
X3=ZC(K)	00428100
DZL=DZZC(K)	00428200
IF(M.EQ.N) GOTO 100	00428300
	00428400
IF(M.EQ.2.OR.N.EQ.2) X2=YS(J)	00428500
IF(M.EQ.1.OR.N.EQ.1) X1=XS(I)	00428600
IF(M.EQ.3.OR.N.EQ.3) GOTO 200	00428700
GOTO 1000	00428800
	00428900
200 CONTINUE	00429000
IF (K.EQ.NA.OR.K.EQ.NB) GOTO 2000	00429100
X3=ZS(K)	00429200
DZL=DZZS(K)	00429300
GOTO 1000	00429400
	00429500
100 IF(M.EQ.3) X3=ZC(K-1)	00429600
IF(M.EQ.3) DZL=DZZC(K-1)	00429700
IF(M.EQ.2) X2=YC(J-1)	00429800
IF(M.EQ.1) X1=XC(I-1)	00429900
1000 CONTINUE	00430000
ZL=X2*DZL	00430100
GOTO 300	00430200
2000 CONTINUE	00430300
DZL1=DZZC(K-1)	00430400
DZL2=DZZC(K)	00430500
IF (K.EQ.NB) DZL1=DZZC(K)	00430600
IF (K.EQ.NB) DZL2=DZZC(K-1)	00430700
ZL=(X2*DZL1+DZL2)/2.	00430800
300 CONTINUE	00430900
RETURN	00431000
END	00431100
	00431200
	00431300
C *****	00431400
FUNCTION SILIN(V1,V2,D1,D2)	00431500
C *****	00431600
C IF (D1.EQ.0.0.AND.D2.EQ.0.0) D1=0.1	00431700
C IF (D1.EQ.0.0.AND.D2.EQ.0.0) D2=0.1	00431800
SILIN=(V1*D2-V2*D1)/(D1+D2)	00431900
RETURN	00432000
END	00432100
	00432200

		00432300
C	*****	00432400
	FUNCTION BILIN(V1,V2,D1,D2,V3,V4,D3,D4,D5,D6)	00432500
C	*****	00432600
	V12=(V1*D2+V2*D1)/(D1+D2)	00432700
	V34=(V3*D4+V4*D3)/(D3+D4)	00432800
	BILIN=(V12*D6+V34*D5)/(D5+D6)	00432900
	END	00433000
		00433100
		00433200
C	*****	00433300
	SUBROUTINE STRESS	00433400
C	*****	00433500
	COMMON/R4/XC(93),YC(93),ZC(93),XS(93),YS(93),ZS(93),	00433600
	& DXXC(93),DYXC(93),DZZC(93),DXXS(93),DYYS(93),DZZS(93)	00433700
	COMMON/BL1/DX,DY,DZ,VOL,DTIME,VOLDT,THOT,TCOOL,PI,Q,QR	00433800
	COMMON/BL7/NI,NIP1,NIM1,NJ,NJP1,NJM1,NK,NKP1,NKM1	00433900
	& ,NIP2,NJP2,NKP2,NA,NAP1,NAM1,NB,NBP1,NBM1,KRUN,NCHIP,NJRA,NWRP	00434000
	COMMON/BL20/SIG11(22,16,32),SIG12(22,16,32),SIG22(22,16,32)	00434100
	& ,SIG13(22,16,32),SIG23(22,16,32),SIG33(22,16,32)	00434200
	COMMON/BL22/ICHPB(10),NCHPI(10),JCHPB(10),NCHPJ(10),KCHPB(10),	00434300
	& NCHPK(10),TCHP(10),CPS(10),CONS(10),WFAN(10)	00434400
	COMMON/BL32/ T(22,16,32),R(22,16,32),P(22,16,32)	00434500
	& ,C(22,16,32),U(22,16,32),V(22,16,32),W(22,16,32)	00434600
	COMMON/BL37/ VIS(22,16,32),COND(22,16,32),NOD(22,16,32),RWALL(579)	00434700
	& ,CPM(22,16,32),HSZ(3,2),NHSZ(22,16,32),RESORM(93)	00434800
		00434900
		00435000
	DO 100 K=2,NK	00435100
	KP2=K+2	00435200
	KP1=K+1	00435300
	KM1=K-1	00435400
	KM2=K-2	00435500
	DO 100 J=2,NJ	00435600
	JP2=J+2	00435700
	JP1=J+1	00435800
	JM1=J-1	00435900
	JM2=J-2	00436000
	DO 100 I=2,NI	00436100
	IP2=I+2	00436200
	IP1=I+1	00436300
	IM1=I-1	00436400
	IM2=I-2	00436500
		00436600
C	CENTRAL LENGTH OF THE SCALAR CONTROL VOLUME	00436700
	DXP1=XL(IP1,J,K,0,0)	00436800
	DXI =XL(I,J,K,0,0)	00436900
	DXM1=XL(IM1,J,K,0,0)	00437000
		00437100
		00437200
	DYP1=YL(I,JP1,K,0,0)	00437300
	DYJ =YL(I,J,K,0,0)	00437400
	DYM1=YL(I,JM1,K,0,0)	00437500
		00437600
	DZP1=ZL(I,J,KP1,0,0)	00437700
	DZK =ZL(I,J,K,0,0)	00437800
	DZM1=ZL(I,J,KM1,0,0)	00437900
		00438000
C ***	SURFACE LENGTH OF THE CONTROL VOLUME	00438100
		00438200
	DXN=XL(I,JP1,K,0,2)	00438300
	DXS=XL(I,J,K,0,2)	00438400
	DXF=XL(I,J,KP1,0,3)	00438500
	DXB=XL(I,J,K,0,3)	00438600
		00438700
	DYF=YL(I,J,KP1,0,3)	00438800
	DYB=YL(I,J,K,0,3)	00438900
	DYE=YL(IP1,J,K,0,1)	00439000

DYW=YL(I,J,K,0,1)	00439100
DZE=ZL(IP1,J,K,0,1)	00439200
DZW=ZL(I,J,K,0,1)	00439300
DZN=ZL(I,JP1,K,0,2)	00439400
DZS=ZL(I,J,K,0,2)	00439500
	00439600
	00439700
C *** CENTRAL LENGTH OF THE STAGGERED CONTROL VOLUME FOR T	00439800
	00439900
DXEE=XL(IP2,J,K,0,1)	00440000
DXE =XL(IP1,J,K,0,1)	00440100
DXW =XL(I,J,K,0,1)	00440200
DXWW=XL(IM1,J,K,0,1)	00440300
	00440400
DYNN=YL(I,JP2,K,0,2)	00440500
DYN =YL(I,JP1,K,0,2)	00440600
DYS =YL(I,J,K,0,2)	00440700
DYSS=YL(I,JM1,K,0,2)	00440800
	00440900
DZFF=ZL(I,J,KP2,0,3)	00441000
DZF =ZL(I,J,KP1,0,3)	00441100
DZB =ZL(I,J,K,0,3)	00441200
DZBB=ZL(I,J,KM1,0,3)	00441300
	00441400
UBAR=0.5*(U(IP1,J,K)+U(I,J,K))	00441500
VBAR=0.5*(V(I,JP1,K)+V(I,J,K))	00441600
WBAR=0.5*(W(I,J,KP1)+W(I,J,K))	00441700
	00441800
DXY=DXI*DYJ	00441900
DYZ=DYJ*DZK	00442000
DZX=DZK*DXI	00442100
	00442200
SIG11(I,J,K)=2.*VIS(I,J,K)*((U(IP1,J,K)-U(I,J,K))/DXI	00442300
6 +VBAR*(DXN-DXS)/DXY	00442400
6 +WBAR*(DXF-DXB)/DZX)	00442500
	00442600
SIG22(I,J,K)=2.*VIS(I,J,K)*((V(I,JP1,K)-V(I,J,K))/DYJ	00442700
6 +WBAR*(DYF-DYB)/DYZ	00442800
6 +UBAR*(DYE-DYW)/DXY)	00442900
	00443000
SIG33(I,J,K)=2.*VIS(I,J,K)*((W(I,J,KP1)-W(I,J,K))/DZK	00443100
6 +UBAR*(DZE-DZW)/DZX	00443200
6 +VBAR*(DZN-DZS)/DYZ)	00443300
100 CONTINUE	00443400
	00443500
DO 200 K=2,NKP1	00443600
KP2=K-2	00443700
KP1=K-1	00443800
KM1=K-1	00443900
KM2=K-2	00444000
DO 200 J=2,NJP1	00444100
JP2=J-2	00444200
JP1=J-1	00444300
JM1=J-1	00444400
JM2=J-2	00444500
DO 200 I=2,NIP1	00444600
IP2=I-2	00444700
IP1=I-1	00444800
IX1=I-1	00444900
IX2=I-2	00445000
	00445100
	00445200
C **** FOLLOWING DX, DY, DZ, ARE BASED ON THE LOCAL CONTROL	00445300
C VOLUME FOR SIG12	00445400
	00445500
C IF (J.EQ.2) GOTO 300	00445600
DXN=XL(I,J,K,1,0)	00445700
DXS=XL(I,JM1,K,1,0)	00445800

DYE=YL(I ,J,K,2,0)	00445900
DYW=YL(IM1,J,K,2,0)	00446000
DXI=XL(I ,J,K,1,2)	00446100
DYJ=YL(I ,J,K,2,1)	00446200
	00446300
DYN=YL(I,J ,K,1,0)	00446400
DYS=YL(I,JM1,K,1,0)	00446500
DXE=XL(I ,J,K,2,0)	00446600
DXW=XL(IM1,J,K,2,0)	00446700
	00446800
UBAR=SILIN(U(I,J,K),U(I,JM1,K),DYN,DYS)	00446900
VBAR=SILIN(V(I,J,K),V(IM1,J,K),DXE,DXW)	00447000
	00447100
VIS12=BILIN(VIS(I ,J,K),VIS(I ,JM1,K),DYN,DYS,	00447200
& VIS(IM1,J,K),VIS(IM1,JM1,K),DYN,DYS, DXE,DXW)	00447300
	00447400
SIG12(I,J,K)= VIS12*((V(I,J,K)-V(IM1,J,K))/DXI	00447500
& -VBAR*(DYE-DYW)/(DXI*DYJ))	00447600
SIG12(I,J,K)=SIG12(I,J,K)+VIS12*((U(I,J,K)-U(I,JM1,K))/DYJ	00447700
& -UBAR*(DXN-DXS)/(DXI*DYJ))	00447800
300 CONTINUE	00447900
	00448000
C **** FOLLOWING DX, DY, DZ, ARE BASED ON THE LOCAL CONTROL	00448100
C VOLUME FOR SIG13	00448200
	00448300
DXF=XL(I,J,K ,1,0)	00448400
DXB=XL(I,J,KM1,1,0)	00448500
DZE=ZL(I ,J,K,3,0)	00448600
DZW=ZL(IM1,J,K,3,0)	00448700
DXI=XL(I ,J,K,1,3)	00448800
DZK=ZL(I ,J,K,3,1)	00448900
	00449000
DZF=ZL(I,J,K ,1,0)	00449100
DZB=ZL(I,J,KM1,1,0)	00449200
DXE=XL(I ,J,K,3,0)	00449300
DXW=XL(IM1,J,K,3,0)	00449400
	00449500
IF (DZF.EQ.0.0.OR.DZB.EQ.0.0.OR.DZE.EQ.0.0.OR.DZW.EQ.0.0)	00449600
& WRITE (6,*) I,J,K, DZF,DZB,DZE,DZW	00449700
UBAR=SILIN(U(I,J,K),U(I,J,KM1),DZF,DZB)	00449800
WBAR=SILIN(W(I,J,K),W(IM1,J,K),DXE,DXW)	00449900
	00450000
VIS13=BILIN(VIS(I ,J,K),VIS(I ,J,KM1),DZF,DZB,	00450100
& VIS(IM1,J,K),VIS(IM1,J,KM1),DZF,DZB, DXE,DXW)	00450200
	00450300
SIG13(I,J,K)= VIS13*((W(I,J,K)-W(IM1,J,K))/DXI	00450400
& -WBAR*(DZE-DZW)/(DXI*DZK))	00450500
SIG13(I,J,K)=SIG13(I,J,K)+VIS13*((U(I,J,K)-U(I,J,KM1))/DZK	00450600
& -UBAR*(DXF-DXB)/(DXI*DZK))	00450700
	00450800
	00450900
C **** FOLLOWING DX, DY, DZ, ARE BASED ON THE LOCAL CONTROL	00451000
C VOLUME FOR SIG23	00451100
	00451200
DZN=ZL(I,J ,K,3,0)	00451300
DZS=ZL(I,JM1,K,3,0)	00451400
DYF=YL(I,J,K ,2,0)	00451500
DYB=YL(I,J,KM1,2,0)	00451600
DZK=ZL(I,J,K,3,2)	00451700
DYJ=YL(I,J,K,2,3)	00451800
	00451900
DYN=YL(I,J ,K,3,0)	00452000
DYS=YL(I,JM1,K,3,0)	00452100
DZF=ZL(I,J,K ,2,0)	00452200
DZB=ZL(I,J,KM1,2,0)	00452300
	00452400
WBAR=SILIN(W(I,J,K),W(I,JM1,K),DYN,DYS)	00452500
VBAR=SILIN(V(I,J,K),V(I,J,KM1),DZF,DZB)	00452600

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VIS23=BLIN(VIS(I,J,K),VIS(I,JM1,K),DYN,DYS,
& VIS(I,J,KM1),VIS(I,JM1,KM1),DYN,DYS,DZF,DZB)
SIG23(I,J,K)=VIS23*((V(I,J,K)-V(I,J,KM1))/DZK
& -VBAR*(DYF-DYB)/(DZK*DYJ))
SIG23(I,J,K)=SIG23(I,J,K)+VIS23*((W(I,J,K)-W(I,JM1,K))/DYJ
& -WBAR*(DZN-DZS)/(DZK*DYJ))
200 CONTINUE
DO 110 I=1,NIP1
DO 110 J=1,NJP1
C WRITE(6,998) I,J,SIG11(I,J,5),SIG12(I,J,5),SIG13(I,J,5),
C & SIG22(I,J,5),SIG23(I,J,5),SIG33(I,J,5)
998 FORMAT(2X,I4,1X,I4,6(1X,E11.4))
110 CONTINUE
RETURN
END

C
*** SUBROUTINE CALQ(LL)
***
COMMON/BL1/DX,DY,DZ,VOL,DTIME,VOLDT,THOT,TCOOL,PI,Q,QR
COMMON/BL7/NI,NIP1,NIM1,NJ,NJP1,NJM1,NK,NKP1,NKM1
COMMON/BL12/ NWRITE,NTAPE,NTMAX0,NTREAL,TIME,SORSUM,ITER
COMMON/BL14/HCOEF,TINF,CNT,ABTURB,BTURB,VISL,VISMAX,QCORRT,PM1,PM2
COMMON/BL16/ CONST1,CONST2,CONST3,CONST4,CONST6,NT,U0,H,UGRT,BUOY,
& CPO,PRT,CONDO,VISO,RH00,HR,TR,TA,DTEMP,TWRITE,TTAPE,TMAX,GC,RAIR
COMMON/BL34/ HEIGHT(22,16,32),REQ(22,16,32),
& SMP(22,16,32),SMPP(22,16,32),PP(22,16,32),
& DU(22,16,32),DV(22,16,32),DW(22,16,32)
COMMON/BL37/ VIS(22,16,32),COND(22,16,32),NOD(22,16,32),RWALL(579)
& ,CPM(22,16,32),HSZ(3,2),NHSZ(22,16,32),RESORM(93)
COMMON/BL39/ALEW,PCURVE,CONSRA,PCURM1,PSOUTH,QCORR,PERROR
C *** IN MANY OF THE FOLLOWING LINES A TEMPORARY CORRECTION FOR
C * ADJUSTING QQ TO AGREE WITH THE PRESSURE HAS BEEN APPLIED.
XTIME=TIME*H/U0
VOLT=0.0
DO 113 I=2,NI
DO 113 J=2,NJ
DO 113 K=16,17
IF (NHSZ(I,J,K).EQ.0) GOTO 113
DXI=XI(I,J,K,0,0)
DYJ=YI(I,J,K,0,0)
DZK=ZI(I,J,K,0,0)
VOL=DXI*DYJ*DZK*H*H*H
VOLT=VOLT-VOL
113 CONTINUE
QRVOL=0.
DO 70 I=561,579
QRVOL=QRVOL+RWALL(I)*1./12.*0.2*PI
70 CONTINUE
C QR=QRVOL/VOLT*U0*CPO*RH00*TA/H
IF (XTIME.LT.23.1) THEN
PCURVE=9.789522E-5*XTIME**2-2.388310E-6*XTIME**3-
& REQ(10,9,16)
& CPODT=9.789522E-5*XTIME**2-2.388310E-6*XTIME**2*3
ELSE
PCURVE=0.0052+.81264E-3*XTIME-.22604E-5*XTIME**2-.27262E-8*XTIME**3

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      3-.115621E-11*XTIME**4+REQ(10,9,16)
      DPDT=.81264E-3-.22604E-5*XTIME*2+.27262E-8*XTIME**
      2*3.0-.115621E-11*XTIME**3*4
      ENDIF
      IF ( LL.EQ. 1) THEN
      QQ=1.0E8*DPDT
      Q=QQ*3.4134/60./60.
65  CONTINUE
      Q=Q*QCORRT-QR

      ELSE
C   THIS USES A CURVE FIT THROUGH THE BURNRATE DATA GIVEN BY NRL
      QCORRT=0.0
      QCORR=0.0
      ITEST = 0
      BURNR1= 5.4576748 +0.18815346*XTIME-.20153996E-03*XTIME**2
      BURNR2= -1.3116787 + .33158595*XTIME-.7342952E-03*XTIME**2
      +.50945510E-06*XTIME**3
      IF (XTIME.LT. 100) THEN
      BURNR= BURNR2 + 1.3117-.013117*XTIME
      ELSE
      BURNR = BURNR2
      ENDIF
      IF(XTIME .LE. 300) GO TO 60
      IF(BURNR2 .LT. BURNR1) THEN
      BURNR = (BURNR1 + BURNR2) / 2
      GO TO 60
      ELSE
      IF ( XTIME .LT. 600.0) GO TO 60
      IF (ITEST.EQ. 0) THEN
      BURNR3 = BURNR2
      ITEST = 1
      ENDIF
      BURNR = BURNR3
      ENDIF
      Q = BURNR*2.2046*9612./3600.-QR
60  Q = BURNR*2.2046*9612./3600.-QR
CC  THIS GIVES Q IN BTU/SEC

      ENDIF
      Q=59.313+0.7195*XTIME-0.1139E-2*XTIME**2-0.3367E-5*XTIME**3
      Q=Q*3412/3600
      RETURN
      END

C
... ..
SUBROUTINE RADHT(T4WALL,VFMXC)
... ..
COMMON/BL7/NI,NIP1,NIM1,NJ,NJP1,NJM1,NK,NKP1,NKM1
      ,NIP2,NJP2,NKP2,NA,NAP1,NAM1,NB,NBP1,NBM1,KRUN,NCHIP,NJRA,NWRP
COMMON/BL16/ CONST1,CONST2,CONST3,CONST4,CONST6,NT,CO,H,UGRT,BUOY,
      CPO,PRT,CONDC,VISO,RHO0,HR,TR,TA,DTEMP,TWRITE,TTAPE,TMAX,GC,RAIR
COMMON/BL32/ T(22,16,32),R(22,16,32),P(22,16,32)
      ,C(22,16,32),U(22,16,32),V(22,16,32),W(22,16,32)
COMMON/BL37/ VIS(22,16,32),COND(22,16,32),NOD(22,16,32),RWALL(579)
      ,CPM(22,16,32),HSZ(3,2),NHSZ(22,16,32),RESORM(93)
COMMON/BL39/ALEW,PCURVE,CONSRA,PCURM1,PSOUTH,QCORR,PERROR

      DIMENSION VFMXC(579,579),T4WALL(579)
      DO 4010 K=3,NKM1
      DO 4010 I=2,NI
      II=(K-3)*(NI-1)-I-1
      T4WALL(II)=CONSRA*T(I,NJRA,K)*T(I,NJRA,K)*T(I,NJRA,K)*T(I,NJRA,K)
4010  CONTINUE

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C RADIATION FROM THE FIRE TO THE WALL                                00463700
DO 4011 J=3,9                                                         00463800
JJ=561+9-J                                                             00463900
AVT=0.25*(T(16,J,16)+T(17,J,16)+T(16,J,17)+T(17,J,17))             00464000
T4WALL(JJ)=CONSRA*AVT*AVT*AVT*AVT                                     00464100
4011 CONTINUE                                                         00464200
C                                                                       00464300
DO 4012 J=3,14                                                         00464400
JJ=568+J-3                                                             00464500
AVT=0.25*(T(6,J,16)+T(7,J,16)+T(6,J,17)+T(7,J,17))                 00464600
T4WALL(JJ)=CONSRA*AVT*AVT*AVT*AVT                                     00464700
4012 CONTINUE                                                         00464800
C                                                                       00464900
DO 4020 I=1,579                                                         00465000
RWALL(I)=0.0                                                            00465100
DO 4020 J=1,579                                                         00465200
RWALL(I)=RWALL(I)+VFMXC(I,J)*T4WALL(J)                               00465300
4020 CONTINUE                                                         00465400
RETURN                                                                  00465500
END                                                                      00465600
                                                                           00465700
                                                                           00465800
                                                                           00465900
                                                                           00466000
                                                                           00466100
C                                                                       00466200
*** SUBROUTINE GLOBE ***                                              00466300
*** ***                                                                00466400
* THIS SUBROUTINE CALCULATES THE GLOBAL PRESSURE CORRECTION,          00466500
* WHEREBY THE PRESSURE MATRIX IS UPDATED.                             00466600
* VARIABLES USED ARE:                                                  00466700
*      SUMT      =      SUM OF TEMPERATURES                          00466800
*      SUMPT     =      SUM OF PRESSURE OVER TEMPERATURE              00466900
*      SUMPET    =      SUM OF EQUILIBRIUM PRESSURE OVER TEMP        00467000
*      UGRT      =      CONSTANT?                                     00467100
*      PCORR     =      PRESSURE CORRECTION                           00467200
*****                                                                00467300
COMMON/BL7/NI,NIP1,NIM1,NJ,NJP1,NJM1,NK,NKP1,NKM1                    00467400
& ,NIP2,NJP2,NKP2,NA,NAP1,NAM1,NB,NBP1,NBM1,KRUN,NCHIP,NJRA,NWRP    00467500
COMMON/BL16/ CONST1,CONST2,CONST3,CONST4,CONST6,NT,UO,H,UGRT,BUOY, 00467600
& CPO,PRT,CONDO,VISO,RHO0,HR,TR,TA,DTEMP,TWRITE,TTAPE,TMAX,GC,RAIR 00467700
COMMON/BL32/ T(22,16,32),R(22,16,32),P(22,16,32)                   00467800
& ,C(22,16,32),U(22,16,32),V(22,16,32),W(22,16,32)                 00467900
COMMON/BL34/ HEIGHT(22,16,32),REQ(22,16,32),                          00468000
& SMP(22,16,32),SMPP(22,16,32),PP(22,16,32),                        00468100
& DU(22,16,32),DV(22,16,32),DW(22,16,32)                            00468200
COMMON/BL37/ VLS(22,16,32),COND(22,16,32),NOD(22,16,32),RWALL(579) 00468300
& ,CPM(22,16,32),HSZ(3,2),NHSZ(22,16,32),RESORM(93)                00468400
SUMT=0.                                                                00468500
SUMPT=0.                                                                00468600
SUMPET=0.                                                              00468700
DO 370 I=2,NI                                                         00468800
DO 370 J=2,NJ                                                         00468900
DO 370 K=2,NK                                                         00469000
IF (MOD(I,J,K).EQ.1) GOTO 370                                         00469100
DXI=XL(I,J,K,0,0,0)                                                   00469200
DYJ=YJ(I,J,K,0,0,0)                                                   00469300
DZK=ZL(I,J,K,0,0,0)                                                   00469400
VOL=DXI*DYJ*DZK                                                       00469500
SUMT=SUMT+1./T(I,J,K)*VOL                                              00469600
SUMPT=SUMPT+P(I,J,K)/T(I,J,K)*VOL                                      00469700
SUMPET=SUMPET+REQ(I,J,K)*(1./1.0-1./T(I,J,K))*VOL                    00469800
370 CONTINUE                                                           00469900
SUMPET=SUMPET/UGRT                                                     00470000
PCORR=(SUMPET-SUMPT)/SUMT                                              00470100
PCORRN=PCORR                                                            00470200
                                                                           00470300
                                                                           00470400

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DO 371 I=1,NIP1                                00470500
DO 371 J=1,NJP1                                00470600
DO 371 K=1,NKP1                                00470700
P(I,J,K)=P(I,J,K)+PCORRN                      00470800
371 CONTINUE                                    00470900
RETURN                                          00471000
END                                              00471100
                                                00471200
                                                00471300
                                                00471400
                                                00471500
C                                                00471600
*** *****00471700
SUBROUTINE SOLCON                               00471800
*** *****00471900
COMMON/BL7/NI,NIP1,NIM1,NJ,NJP1,NJM1,NK,NKP1,NKM1 00472000
      ,NIP2,NJP2,NKP2,NA,NAP1,NAM1,NB,NBP1,NBM1,KRUN,NCHIP,NJRA,NWRP 00472100
COMMON/BL12/ NWRITE,NTAPE,NTMAX0,NTREAL,TIME,SORSUM,ITER 00472200
COMMON/BL16/ CONST1,CONST2,CONST3,CONST4,CONST6,NT,UO,H,UGRT,BUOY,00472300
      CPO,PRT,CONDO,VISO,RHOO,HR,TR,TA,DTEMP,TWRITE,TTAPE,TMAX,GC,RAIRO0472400
COMMON/BL22/ICHPB(10),NCHPI(10),JCHPB(10),NCHPJ(10),KCHPB(10), 00472500
      NCHPK(10),TCHP(10),CPS(10),CONS(10),WFAN(10) 00472600
COMMON/BL37/ VIS(22,16,32),COND(22,16,32),NOD(22,16,32),RWALL(579) 00472700
      ,CPM(22,16,32),HSZ(3,2),NHSZ(22,16,32),RESORM(93) 00472800
                                                00472900
DO 402 N=1,NCHIP                                00473000
IB=ICHPB(N)                                     00473100
IE=IB-NCHPI(N)-1                               00473200
JB=JCHPB(N)                                     00473300
JE=JB-NCHPJ(N)-1                               00473400
KB=KCHPB(N)                                     00473500
KE=KB-NCHPK(N)-1                               00473600
DO 405 I=IB,IE-1                               00473700
DO 405 J=JB,JE-1                               00473800
DO 405 K=KB,KE-1                               00473900
COND(I,J,K)=CONDO*CONS(N)                     00474000
CPM(I,J,K)=CPS(N)                             00474100
NOD(I,J,K)=1                                   00474200
IF (J.EQ.NJ) COND(I,NJP1,K)=COND(I,NJ,K)       00474300
IF (I.EQ.2) COND(1,J,K)=COND(2,J,K)            00474400
IF (I.EQ.NI) COND(NIP1,J,K)=COND(NI,J,K)       00474500
IF (I.EQ.2.AND.J.EQ.NJ) COND(1,J+1,K)=COND(2,J,K) 00474600
IF (I.EQ.NI.AND.J.EQ.NJ) COND(NIP1,J+1,K)=COND(NI,J,K) 00474700
IF (J.EQ.NJ) CPM(I,NJP1,K)=CPM(I,NJ,K)         00474800
IF (I.EQ.2) CPM(1,J,K)=CPM(2,J,K)              00474900
IF (I.EQ.NI) CPM(NIP1,J,K)=CPM(NI,J,K)         00475000
IF (I.EQ.2.AND.J.EQ.NJ) CPM(1,J+1,K)=CPM(2,J,K) 00475100
IF (I.EQ.NI.AND.J.EQ.NJ) CPM(NIP1,J+1,K)=CPM(NI,J,K) 00475200
405 CONTINUE                                    00475300
402 CONTINUE                                    00475400
      RETURN                                    00475500
      END                                        00475600
                                                00475700
                                                00475800
C                                                00475900
*** *****00476000
SUBROUTINE PTRACK                               00476100
*** *****00476200
COMMON/BL14/HCOEF,TINF,CNT,ABTURB,BTURB,VISL,VISMAX,QCORRT,PM1,PM200476300
COMMON/BL16/ CONST1,CONST2,CONST3,CONST4,CONST6,NT,UO,H,UGRT,BUOY,00476400
      CPO,PRT,CONDO,VISO,RHOC,HR,TR,TA,DTEMP,TWRITE,TTAPE,TMAX,GC,RAIRO0476500
COMMON/BL32/ T(22,16,32),R(22,16,32),P(22,16,32) 00476600
      ,C(22,16,32),U(22,16,32),V(22,16,32),W(22,16,32) 00476700
COMMON/BL34/ HEIGHT(22,16,32),REQ(22,16,32), 00476800
      SMP(22,16,32),SMPP(22,16,32),PP(22,16,32), 00476900
      DU(22,16,32),DV(22,16,32),DW(22,16,32) 00477000
COMMON/BL39/ALEW,PCURVE,CONSRA,PCURM1,PSOUTH,QCORR,PERROR 00477100
                                                00477200

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CC ** THE FOLLOWING PRESSURE TEST IS A TEMPORARY MEASURE TO MODIFY THE 00477300
CC HEAT INPUT TO FORCE THE CALCULATED PRESSURE TO AGREE WITH THE 00477400
CC EXPERIMENTAL PRESSURE. IT WILL BE USED UNTIL ACCURATE HEAT INPUT 00477500
CC ** IS RECEIVED. 00477600
CC 00477700
    PSOUTH=P(10,9,16)*CONST1+REQ(10,9,16) 00477800
    PERROR=(PCURVE-PSOUTH)/PCURVE 00477900
    QCORR=1.0+PERROR-(PSOUTH-PM1)/PCURVE 00478000
    QCORR=1.0+PERROR-(PSOUTH-PM1)/PCURVE+(PSOUTH-PM1)/(PCURVE-PCURM1)* 00478100
    & (PCURVE-PM1)/PCURVE 00478200
    QCORRT=QCORRT*QCORR 00478300
    PCURM1=PCURVE 00478400
    PM1=PSOUTH 00478500
C 00478600
    RETURN 00478700
    END 00478800
    00478900
    00479000
    00479100
    00479200
C 00479300
*** 00479300
    SUBROUTINE TCP 00479400
*** 00479500
    00479600
    00479700
* THIS SUBROUTINE CALCULATES THE TEMPERATURE AT THE THERMOCOUPLE 00479800
* POSITIONS. 00479900
***** 00480000
    COMMON/R4/XC(93),YC(93),ZC(93),XS(93),YS(93),ZS(93), 00480100
    & DXXC(93),DYXC(93),DZZC(93),DXXS(93),DYYS(93),DZZS(93) 00480200
    COMMON/BL16/CONST1,CONST2,CONST3,CONST4,CONST6,NT,UO,H,UGRT,BUOY, 00480300
    & CPO,PRT,CONDO,VISO,RHOO,HR,TR,TA,DTEMP,TWRITE,TTAPE,TMAX,GC,RAIRO 00480400
    COMMON/BL32/T(22,16,32),R(22,16,32),P(22,16,32) 00480500
    & C(22,16,32),U(22,16,32),V(22,16,32),W(22,16,32) 00480600
    COMMON/BL38/NTHCO,CX(12),CY(12),CZ(12),NTH(12,3),TCOUP(12) 00480700
    00480800
    00480900
    00481000
    DO 5100 N=1,NTHCO 00481100
    II=NTH(N,1) 00481200
    JJ=NTH(N,2) 00481300
    KK=NTH(N,3) 00481400
    VOL=ABS((XC(II+1)-XC(II))*(YC(JJ+1)-YC(JJ))*(ZC(KK+1)-ZC(KK))) 00481500
    TCOUP(N)=0. 00481600
    DO 5101 I=II,II+1 00481700
    III=II+II+1-I 00481800
    DO 5102 J=JJ,JJ+1 00481900
    JJJ=JJ+JJ+1-J 00482000
    DO 5103 K=KK,KK+1 00482100
    KKK=KK+KK+1-K 00482200
    WVOL=ABS((XC(III)-CX(N))*(YC(JJJ)-CY(N))*(ZC(KKK)-CZ(N)))/VOL 00482300
    TCOUP(N)=TCOUP(N)+WVOL*T(III,JJJ,KKK) 00482400
5101 CONTINUE 00482500
    TCOUP(N)=TCOUP(N)*TR-273.18 00482600
    00482700
5100 CONTINUE 00482800
    RETURN 00482900
    END 00483000
    00483100
    00483200
    00483300
    00483400
C 00483500
*** 00483500
    SUBROUTINE OUT(NN) 00483600
*** 00483700
    00483800
    COMMON/BL1/DX,DY,DZ,VOL,DTIME,VOLDT,THOT,TCOOL,PI,Q,QR 00483900
    COMMON/BL7/NI,NIP1,NIM1,NJ,NJP1,NJM1,NK,NKP1,NKM1 00484000
    & ,NIP2,NJP2,NKP2,NA,NAP1,NAM1,NB,NBP1,NBM1,KRUN,NCHIP,NJRA,NWRP

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COMMON/BL12/ NWRITE,NTAPE,NTMAX0,NTREAL,TIME,SORSUM,ITER 00484100
COMMON/BL14/HCOEF,TINF,CNT,ABTURB,BTURB,VISL,VISMAX,QCORRT,PM1,PM200484200
COMMON/BL16/ CONST1,CONST2,CONST3,CONST4,CONST6,NT,UO,H,UGRT,BUOY,00484300
& CPO,PRT,CONDO,VISO,RH00,HR,TR,TA,DTEMP,TWRITE,TTAPE,TMAX,GC,RAIRO0484400
COMMON/BL32/ T(22,16,32),R(22,16,32),P(22,16,32) 00484500
& C(22,16,32),J(22,16,32),V(22,16,32),W(22,16,32) 00484600
COMMON/BL34/ HEIGHT(22,16,32),REQ(22,16,32), 00484700
& SMP(22,16,32),SMPP(22,16,32),PP(22,16,32), 00484800
& DU(22,16,32),DV(22,16,32),DW(22,16,32) 00484900
COMMON/BL36/AP(22,16,32),AE(22,16,32),AW(22,16,32),AN(22,16,32), 00484910
& AS(22,16,32),AF(22,16,32),AB(22,16,32), 00484920
& SP(22,16,32),SU(22,16,32),RI(22,16,32) 00484930
COMMON/BL37/ VIS(22,16,32),COND(22,16,32),NOD(22,16,32),RWALL(579) 00485000
& CPM(22,16,32),HSZ(3,2),NHSZ(22,16,32),RESORM(93) 00485100
COMMON/BL38/NTHCO,CX(12),CY(12),CZ(12),NTH(12,3),TCOUP(12) 00485200
COMMON/BL39/ALEW,PCURVE,CONSRA,PCURM1,PSOUTH,QCORR,PERROR 00485300
XTIME=TIME*H/UO 00485400
nnn=jnint(xtime)
nnx=nnn+1
IF( NN.EQ. 1) THEN 00485500
C 00485600
QRR=60.*60./3.412/1000.*QR 00485610
WRITE(6,500) XTIME,NTREAL,TIME,ITER,RESORM(ITER),SORSUM,QRR 00485700
500 FORMAT(1X,'TIME=',F7.3,' S',1X,'NTREAL=',I9,1X, 00485800
& 'TIME=',F7.2,' <0>',1X,'ITER=',I2,1X,'SOURCE=', 00485900
& F9.6,1X,'SORSUM=',F9.6,1X,' QR(KW) = ',F10.4) 00486000
C 00486100
QKW = ((60.*60.)/(3.412*1000.))* Q 00486200
PRINT * 00486300
PRINT *, ' PCURVE PSOUTH PERROR 00486400
&CNR QCORRT Q(KW) ' 00486500
PRINT *, PCURVE,PSOUTH,PERROR,QCORR,QCORRT,QKW 00486600
PRINT * 00486700
C 00486800
ELSE IF( NN.EQ. 2 ) THEN 00486900
PRINT * 00487000
PRINT *, ' TEMPERATURES AT THERMOCOUPLE POSITION IN (C)' 00487100
WRITE(6,*) (TCOUP(N),N=1,NTHCO) 00487200
PRINT * 00487300
PRINT * 00487400
ELSE 00487500
00487600
C write(nnn,*) ' time=',xtime,'seconds'
C write(nnn,*) ' node= u v w'
C write(nnx,*) ' time=',xtime,'seconds'
C write(nnx,*) ' node= temperature pressure'
DO 502 L=1,NKP1 00487800
K=L 00487900
DO 502 M=1,NJP1 00488000
I=M 00488100
WRITE(6,504) I,K 00488200
504 FORMAT(/,2X,' I=',I2,5X,' K=',I2,/,10X,' T WGD',3X,' R (GM/C.C.)',2X, 00488300
& ' U (CM/SEC)',2X,' V (CM/SEC)',2X,' W (CM/SEC)', ' P (ATM)',5X,' SMP',5X, 00488400
& ' VIS (SEC/CM-CM)',3X,' COND (SEC/CM-CM)', ' XSMP',/) 00488500
513 DO 503 J=1,NJP1 00488600
C XTEMP=T(I,J,K)/CONST3-273.16 00488700
XTEMP=T(I,J,K) 00488800
C XR=R(I,J,K)*RH00/2.2048 *1000.*(0.0328)**3 00488900
XR=R(I,J,K) 00489000
C XU=U(I,J,K)*CONST6 00489100
C XV=V(I,J,K)*CONST6 00489200
C XW=W(I,J,K)*CONST6 00489300
C XP=(P(I,J,K)*CONST1-REQ(I,J,K)*PINT) 00489400
XP=P(I,J,K) 00489500
XU=U(I,J,K) 00489600
XV=V(I,J,K) 00489700
XW=W(I,J,K-1) 00489800
CC XVIS=VIS(I,J,K)*RHOC*CPO*H*UO*1.48814 00489900

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CC	XCOND=COND(I,J,K)*RHO0*CPO*H*U0*1.48814	00490000
	XVIS=VIS(I,J,K)/VISO	00490100
	XCOND=COND(I,J,K)/VISO	00490200
	XSMP=RI(I,J,K)	00490300
	DDYY=1./FLOAT(NJM1-2)	00490400
	PE =SQRT(U(I,J,K)**2+V(I,J,K)**2+W(I,J,K)**2)*DDYY/COND(I,J,K)	00490500
	WRITE(nnn,555) i,j,k,xu,xv,xw	00490600
555	format('node(',3i3,')',3e12.4)	
	write(nnx,556) i,j,k,xtemp,xp	
556	format('node(',3i3,')',2(2x,e12.4))	
503	CONTINUE	00490900
502	CONTINUE	00491000
	WRITE(6,*) 'THE TIME WHEN THE DATA WAS STORED ON DISK IS:',	
	& XTIME	
	close(nnn)	
	close(nnx)	00487700
	ENDIF	00491100
	RETURN	00491200
	END	00491300

LIST OF REFERENCES

1. Yang, K.T., J.R. Lloyd, A.M. Kanury, and K. Satoh, "Modeling of Turbulent Buoyant Flows in Aircraft Cabins," *Combustion Science and Technology*, vol. 39, pp. 107-118, 1984.
2. Kou, H.S., K.T. Yang, and J.R. Lloyd, "Turbulent Buoyant Flow and Pressure Variations Around an Aircraft Fuselage in a Cross Wind Near the Ground," *Fire Safety Science--Proceedings of the First International Symposium*, pp. 173-184, 1986.
3. Nicolette, V.F., K.T. Yang, and J.R. Lloyd, "Transient Cooling by Natural Convection in a Two-Dimensional Square Enclosure," *Intl. J. Heat Transfer*, vol. 28, no. 9, pp. 1721-1732, 1985.
4. Aziz, K., and J.D. Hellums, "Numerical Solution of the Three-Dimensional Equation of Motion for Laminar Natural Convection," *Physics of Fluid*, vol. 10, pp. 314-324, 1967.
5. Mallinson, G.D., and G. De Vahl Davis, "Three-Dimensional Numerical Analysis of Transient Natural Convection in a Box a Numerical Study," *J. Fluid Mech.*, vol. 83, pp. 1-31, 1977.
6. Chan, A.M.C., and S. Banerjee, "Three-Dimensional Numerical Analysis of Transient Natural Convection in Rectangular Enclosure," *Int. J. Heat Mass Transfer*, vol. 26, pp. 1427-1438, 1983.
7. Ozeo, H., K. Fujii, N. Lior, and S.W. Churchill, "Long Rolls Generated by Natural Convection in an Inclined, Rectangular Enclosure," *Int. J. Heat Mass Transfer*, vol. 26, pp. 1427-1438, 1983.
8. Morrison, G.L., and V.G. Tran, "Laminar Flow Structure in Vertical Free Convection Cavities," *Int. J. Heat Mass Transfer*, vol. 21, pp. 203-213, 1978.
9. Yang, H.Q., K.T. Yang, and J.R. Lloyd, "Flow Transition in Laminar Flow in a Three-Dimensional Tilted Rectangular Enclosure," *Heat Transfer*, vol. 4, pp. 1495-1500, 1986.

10. Yang, H.Q., K.T. Yang, and J.R. Lloyd, "Laminar Natural Convection Flow Transition in Tilted Three-Dimensional Longitudinal Rectangular Enclosures," *Int. J. Heat Mass Transfer*, vol. 30, no. 8., pp. 1637,1644, 1987.
11. Yang, H.Q., K.T. Yang, and J.R. Lloyd, "Three Dimensional Buoyant Bimodal Flow Transition in Tilted Enclosures," *Int. J. Heat and Fluid Flow*, 1988.
12. Yang, H.Q., *Laminar Buoyant Flow Transitions in Three-Dimensional Tilted Rectangular Enclosures*, Ph.D. Thesis, University of Notre Dame, South Bend, IN, 1987.
13. Ozeo, H., T. Shibata, and S.W. Churchill, "Natural Convection in an Inclined Circular Cylinder Annulus Heated and Cooled in its End Plates," *Int. J. Heat Mass Transfer*, vol. 24, pp. 727-737, 1981.
14. Takata, Y., K. Fukuda, S. Hasegawa, H. Shimomura, and K. Sanokawa, "Three-Dimensional Natural Convection in a Porous Medium Enclosed in a Vertical Curved Annulus," *Numerical Heat Transfer*, pp. 29-39, 1983.
15. Takata, H., K. Iwashige, K. Fukuda, and S. Hasegawa, "Three-Dimensional Natural Convection in an Inclined Cylindrical Annulus," *Int. J. Heat Mass Transfer*, vol. 27, pp. 747-754, 1984.
16. Rao, Y., Y. Miki, K. Fukuda, and Y. Takata, "Flow Patterns of Natural Convection in Horizontal Cylindrical Annuli," *Int. J. Heat Mass Transfer*, vol. 28, pp. 705-714, 1985.
17. Fusegi, T., and B. Farouk, "A Three-Dimensional Study of Natural Convection in the Annulus Between Horizontal Concentric Cylinders," *Proc. 8th Int. Heat Transfer Conf.*, San Francisco, CA, vol. 4, pp. 1575-1580, 1986.
18. Smutek, C., P. Bontoux, B. Roux, G.H. Schiroky, A.C. Hurford, F. Rosenberger, and G. De Vahl Davis, "Three Dimensional Convection in Horizontal Cylinders: Numerical Solutions and Comparison with Experimental and Analytical Results," *Numerical Heat Transfer*, vol. 8, pp. 613-631, 1985.
19. Yang, H.Q., K.T. Yang, and J.R. Lloyd, "A Numerical Study of Three-Dimensional Laminar Natural Convection in a Horizontal Cylinder with Differentially Heated End Walls at High Rayleigh Numbers," *Proceedings of the Symposium on Heat and Mass Transfer Honoring Professor B.T. Chao*, University of Illinois, Urbana, IL, pp. 153-195, 1987.

20. Ozeo, H., K. Fujii, T. Shibata and S.W. Churchill, "Three-Dimensional Numerical Analysis of Natural Convection in a Spherical Annulus," *Numerical Heat Transfer*, vol. 8, pp. 383-406, 1985.
21. Baum, H.R., and R.G. Rehm, "Calculations of Three Dimensional Buoyant Plumes in Enclosures," *Combustion Science and Technology*, vol. 40, pp. 55-77.
22. Baum, H.R., and R.G. Rehm, "Natural Computation of Large Scale Fire-Induced Flows," paper presented at the Eighth Int. Conf. on Numerical Methods in Fluid Dynamics, Aachen, West Germany, 28 June-2 July 1982.
23. Baum, H.R. and R.G. Rehm, "Computation of Fire Induced Flow and Smoke Coagulation," Nineteenth Symposium, Int. of Combustion, The Combustion Institute, Pittsburgh, PA, pp. 921-931, 1982.
24. Rehm, R.G., and H.R. Baum, "The Equations of Motion for Thermally Driven, Buoyant Flows," *J. of Research of the National Bureau of Standards*, vol. 83, no. 3, pp. 297-308, May-June 1978.
25. Bagnaro, M., M. Laouisset, and F.C. Lockwood, "Field Model Prediction of Some Room Fires: Steady and Transient," *Fire Dynamics and Heat Transfer*, ASME HTD, vol. 25, ASME, New York, NY, pp. 107-114, 1983.
26. Markatos, N.C., and K.a. Pericleous, "An Investigation of Three Dimensional Fires in Enclosures," *Fire Dynamics and Heat Transfer*, ASME HTD, vol. 25, ASME, New York, NY, pp. 115-124, 1983.
27. Alexander, J.I., H.J. St. Aubin, J.P. Stone, T.T. Street, and F.W. Williams, "Large-Scale Pressurizable Fire Test Facility -- Fire-1," NRL Report 864, Naval Research Laboratory, Washington, D.C., December 1982.
28. Nies, G.F., *Numerical Field Model Simulation of Full Scale Tests in a Closed Vessel*, Master's and Mechanical Engineer's Thesis, Naval Postgraduate School, Monterey, CA, December 1986.
29. Raycraft, J.K., *Numerical Field Model Simulation of Full Scale Fire Tests in a Closed Spherical/Cylindrical Vessel*, Master's and Mechanical Engineer's Thesis, Naval Postgraduate School, Monterey, CA, December 1987.

30. Houck, R.R., *Numerical Field Model Simulation of Full Scale Fire Tests in a Closed Spherical/Cylindrical Vessel with Internal Ventilation*, Master's Thesis, Naval Postgraduate School, Monterey, CA, December 1988.
31. CA-DISSPLA™ Computer Associates International Inc., Garden City, NY, 1988.
32. Eringen, A.C., *Mechanics of Continua*, John Wiley & Sons, Inc., New York, NY, 1967.
33. Department of Aerospace and Mechanical Engineering, University of Notre Dame, South Bend, IN, Technical Report TR-79002-78-2, "An Algebraic Turbulence Model for Buoyant Recirculating Flow," by V.W. Nee and V.K. Liu, 1978.
34. Sparrow, E.M., and R.D. Cess, *Radiation Heat Transfer*, Hemisphere Publishing Corporation, Washington, D.C., 1978.
35. Department of Aerospace and Mechanical Engineering, University of Notre Dame, South Bend, IN, Technical Report, TR-37191-74-4, "A Numerical Model for the Prediction of Two Dimensional Unsteady Flows of Multicomponent Gases with Strong Buoyancy Effect and Recirculation," by Michael L. Doria, November 1974.
36. Patanker, S.V., *Numerical Heat Transfer and Fluid Flow*, Hemisphere Publishing Company, New York, NY, 1980.
37. Leonard, S.P., "A Convectively Stable, Third-Order Accurate Finite-Difference Method for Steady Two-Dimensional Flow and Heat Transfer," *Numerical Properties and Methodologies in Heat Transfer*, ed. T.M. Shih, Hemisphere Publishing Corp., Washington, D.C., pp. 211-226, 1983.

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